RESEARCH ARTICLE | NOVEMBER 07 2019

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AIP Conf. Proc. 2169, 030003 (2019)
https://doi.org/10.1063/1.5132653

Determination of Internal Parasitic of Photovoltaic Polycrystalline Silicon Hooray MCP-12 under Direct Sunlight Using the Lambert-W Function

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Abstract. The performance of photovoltaic modules (PV) to produce the electric energy is determined by parasitic internal resistance consisting of series and parallel resistance (R_s and R_{sh}). An increase in internal resistance implies a decrease in the quality of output analytically. In this research, we demonstrate the modeling of polycrystalline PV module, which is available in the market using the Lambert-W function and simple experiment by extracting the voltage current (I-V) parameters under dark current conditions by providing a screen in the module. This condition results in relatively small currents and voltages, in accordance with most regions in Indonesia, which have relatively less sunlight due to changing seasons, but are not in the repair of the PV module's internal parasitic resistance. The I–V characteristic of PV was measured using normal irradiance at a temperature of 30°C for a short period of 5 minutes to preserve constant illumination. A maximum open circuit voltage V_{oc} of 16.9V and short circuit current I_{sc} of 0.93 A are denoted in the I-V curve while the maximum output power P_{max} is obtained for 14.08 V and 0.82 A. Using the Lambert-W function which is modified based on the ideal equation of solar cells in the PV module, the parasitic internal resistance R_s and R_{sh} are then calculated resulting in 1.5 Ω and 107.5 Ω respectively. This internal resistance obtained from this model shows an internal loss and decrease performance due to cell-to-cell contact with the PV module during its operation period.

INTRODUCTION

Renewable energy sources from photovoltaic-based solar energy (PV) plays a major role globally and it is currently possible to change the electricity network used to be a Smart Grid where feedback between electricity producers and consumers plays an important role for stability and saving power consumption [1]. Solar cells are configured in series and parallel which is coated with waterproof and weather change resistant material referred as photovoltaic modules, PV. Nowadays, many PV modules are available in the market and the mass production of PV modules requires detailed information about solar cell parameters. This information is very crucial that can determine the performance of the module and also needed to optimize the manufacturing process for scientific research. The related information is to decrease the PV module power quality which is influenced by the flowing currents and changes in resistance due to connections contact. This also will ultimately the utility of solar cell [2]. PV module specifications commonly show performance under standard testing conditions (STC), with limited information about non-STC conditions. Meanwhile, PV performance is influenced by radiation, temperature, irradiance spectral composition, angle of irradiance events and other parameter [3]. Specifications are partially provided, to consumers only about the effects of radiation and temperature [4]. These characteristic changes can be illustrated in the current to voltage (I-V) characteristic curve [5].

Photovoltaic efficiency is dependent on cell temperature since overheating causes a decrease in the energy produced. The measurement location determines also the PV to produce different amounts of power in a certain time

The 8th National Physics Seminar 2019
AIP Conf. Proc. 2169, 030003-1–030003-7; https://doi.org/10.1063/1.5132653
Published by AIP Publishing. 978-0-7354-1916-2/$30.00

interval [6]. The analysis and evaluation methods of PV module parameters have been studied and carried out, such as a simple method by combining empirical and single diode methods to obtain saturation current parameters (I_0), series resistance (R_s) and parallel resistance (R_{sh}) for ZnO cell solar / CDs / Cu (In, Ge) through a graph of dark current I (V) currents [7]. Another method, the Lambert-W function, is used to characterize I-V curves that affect the value of series and parallel internal resistances [8]. This method obtains significant data compared to experimental data and new methods that are efficient to analyze and evaluate PV module parameters. Other experiments were carried out by measuring internal series resistance and maximum power in Standard Test Conditions (STC) [9]. The new model has been developed to determine a PV module parameter estimation [10]. Previous research has been conducted to evaluate the value of internal resistance of photovoltaic panel (PV) modules based on the modeling of the normal light and dark current I (V) curve with empirical equations. This research requires several experiments to obtain empirical resistance and require the time of the experiment. Various parameters are submitted into the empirical equation implies a lack of time efficiency for the calculation of internal parasite resistance.

In this research, the internal parasitic resistance is evaluated using the Lambert-W function for PV module of polycrystalline Hooray MCP-2. The parameters needed to determine R_s and R_{sh} are obtained from the modeling of the current and voltage slope from the experiment under direct sunlight exposure. Direct exposure to the PV modules was filtered using a screen to produce a relatively small and safe current for the I-V measuring circuit. Using this exposure configuration, it is expected that the parameters obtained can also to be used to determine the R_s and R_{sh} parameters using the Lambert-W function. In the previous works, the R_s and R_{sh} were generally determined using the I-V curve modeling at normal irradiation conditions and produced relatively large currents. The results of the internal parasitic resistance of R_s and R_{sh} can provide information on the ability of solar cells to generate power and the depreciation of output due to various internal and external factors.

METHOD

Experiments were carried out by direct sunlight carried out in a short interval < 5 minutes so that measurements avoid being influenced by the environment temperature and the change of the sunlight intensity [7]. The experimental results in the form of current and voltage curves I-V using data acquisition modules that have been configured based on Arduino Uno ATmega 328P type INA219 consisting of analog signals and converted. Block diagram of PV module I-V measurements is shown in Fig. 1.

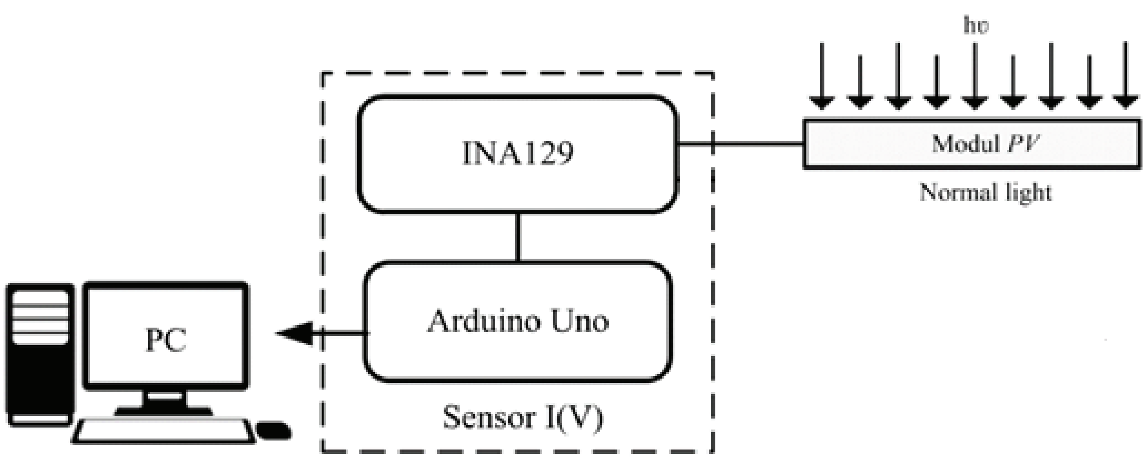

FIGURE 1. Block diagram of PV module I-V measurements

Figure. 1 shows the measurement circuit which consists of PV modules, a current sensor INA219 module for data acquiring and a microcontroller that has a special function as an I2C / TWI / IIC pin, synchronous with a serial data cable (SDA) and serial clock (SCL) for data processing. Furthermore, the load resistance R_L is then varied to generate the I-V curve, as shown in Fig. 2a.

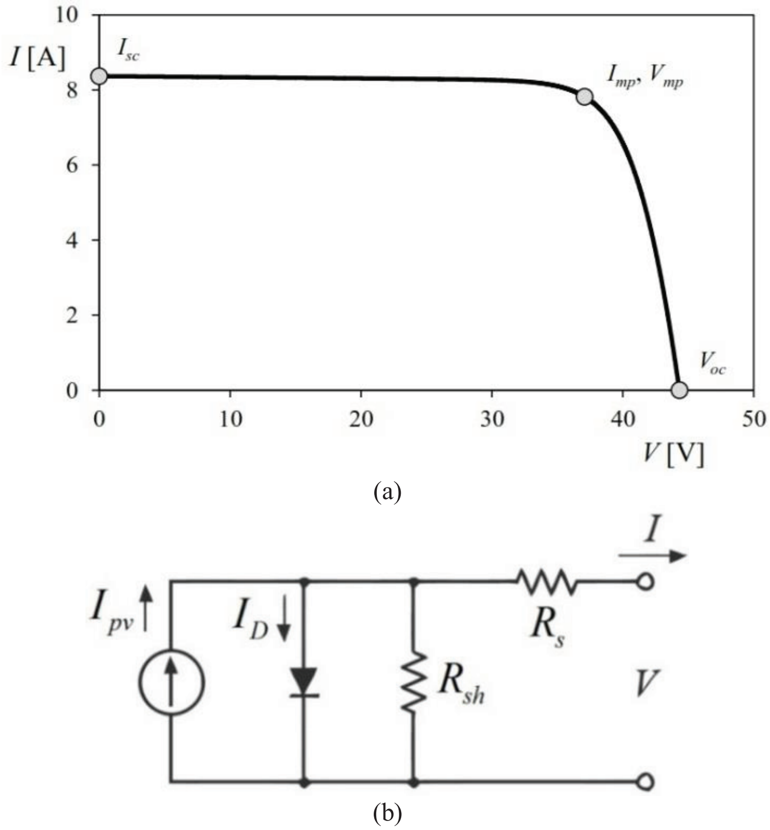

FIGURE 2. (a) I-V curve of PV modules, (b) the equivalent circuit of the ideal PV cell [11].

The PV characteristics represented by I-V curve will produce a solar cell equation model based on equivalent circuits with a diode in Fig. 2b and can be written as an equation (1).

$$I = I_{ph} - I_0\left[\exp\left(\frac{V + I \cdot R_s}{a \cdot V_T}\right) - 1\right] - \frac{V + I \cdot R_s}{R_{sh}} \tag{1}$$

Based on the I-V characteristics, 3 performance parameter points are defined, namely:

- Short circuit current is the maximum current that occurs when the resistance is very low (R ~ 0) and the voltage is zero (V ~ 0). This condition produces a current value equal to the output current (I_{sc} = I) obtained by equation (2).

$$I_{sc} = I_{ph} - I_0\left[\exp\left(\frac{I_{sc} \cdot R_s}{a \cdot V_T}\right) - 1\right] - \frac{I \cdot R_s}{R_{sh}} \tag{2}$$

- Open circuit voltage (V_{oc}) is the maximum voltage that occurs when there is no current passing through the solar cell. This condition produces an output current equal to zero (I = 0) obtained by equation (3).

$$0 = I_{ph} - I_0\left[\exp\left(\frac{V_{oc}}{a \cdot V_T}\right) - 1\right] - \frac{V_{oc}}{R_{sh}} \tag{3}$$

- Maximum power is power at the maximum output operating point, also called the maximum power point (MPP) which I = I_{mp} and V = V_{mp} is obtained by equation (4).

$$I_{mp} = I_{ph} - I_0\left[\exp\left(\frac{V_{mp} + I_{mp} \cdot R_s}{a \cdot V_T}\right) - 1\right] - \frac{V_{mp} + I_{mp} \cdot R_s}{R_{sh}} \tag{4}$$

- The maximum power point is zero (P = 0) as the photovoltaic current is zero (I_{ph} = 0), equation (5) and is obtained.

$$-\frac{I_{mp}}{V_{mp}} = -\frac{I_0}{a\cdot V_T}\left(1-\frac{I_{mp}\cdot R_s}{V_{mp}}\right)-\left[\exp\left(\frac{V_{mp}+I_{mp}\cdot R_s}{a\cdot V_T}\right)-1\right]-\frac{1}{R_{sh}}\left(1-\frac{I_{mp}\cdot R_s}{V_{mp}}\right) \quad (5)$$

Equation (1) to (5) depicted coefficients for determination of parasitic resistance where I is the output current, V is the output voltage, I_{pv} is the photocurrent, I_0 is the saturation current, R_s is series circuit resistance, R_{sh} is shunt resistance, n is the cell number, ɑ is the ideal diode factor, V_{oc} is the open circuit voltage (V), I_{sc} is the short circuit current (A), V_{mp} is the maximum point voltage (V), I_{mp} is the maximum point current (A) and V_T = kBT/q is the thermal voltage. The specifications of the Polycrystalline Hooray MCP-2 Silicon PV module are shown in Tab. 1 and the experimental data setup is shown in Fig. 3.

TABLE 1. PV module specifications [12].

Specifications	Hooray 100MCP-2
Output power P_{max} (Wp)	100
Open circuit voltage V_{oc} (V)	21.5
Saturation current I_{sc} (A)	6.46
Maximum voltage V_{mp} (V)	17.5
Maximum current I_{mp} (A)	5.72

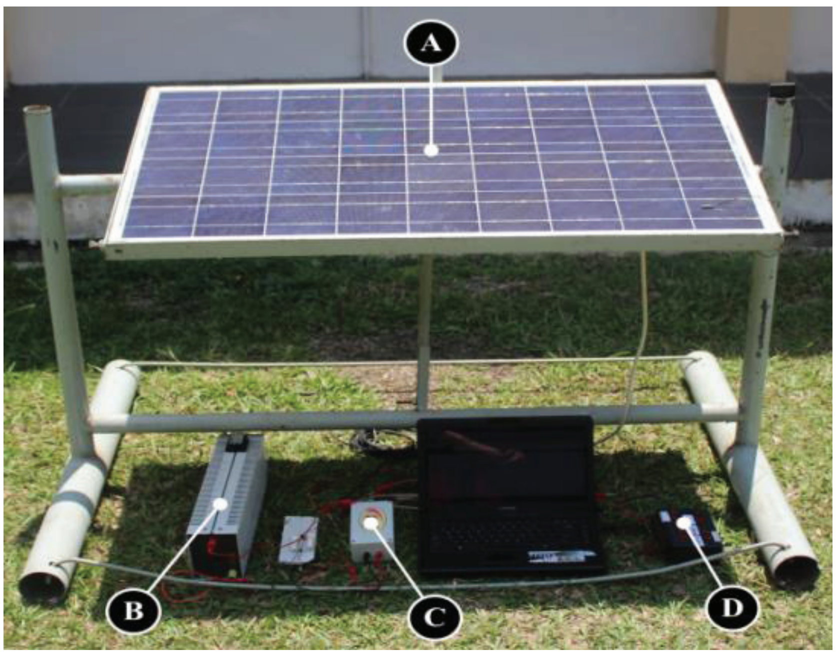

FIGURE 3. Experimental set up of PV module consist of A: Hooray MCP-12 polycrystalline type module, B: load resistance (0-100Ω), C: Data acquisition module and D: switch

The Lambert-W function is an Omega function or a logarithmic multiplication, also known as an inverse *e* relation function of $y = xe^x$ which is e^w an exponent function with aan equationorm of function can be written as equation (6) below [13].

$$x = W(y) \quad (6)$$

where W is the Lambert-W function.

The solution to the equations (1) to (5) can be expressed using the Lambert-W function based on equation (6).

$$R_S = A(W_{-1}(B\ \exp\ (C)) - (D + C)) \tag{7}$$

with:

$$A = \frac{a \cdot V_T}{I_{mp}}$$

$$B = \frac{V_{mp}(2I_{mp} - I_{sc})}{(V_{mp}I_{sc} + V_{oc}(I_{mp} - I_{sc})}$$

$$C = -\frac{2V_{mp} - V_{oc}}{a \cdot V_T} + \frac{(V_{mp}I_{SC} - V_{oc}I_{mp})}{(V_{mp}I_{SC} + V_{oc}(I_{mp} - I_{SC}))}$$

$$D = \frac{V_{mp} - V_{oc}}{a \cdot V_T}$$

The parasitic shunt internal values are obtained by the following equation:

$$R_{Sh} = -\frac{(V_{mp} - I_{mp}R_s)(V_{mp} - R_s(I_{sc} - I_{mp}) - aV_T)}{(V_{mp} - I_{mp}R_s)(I_{sc} - I_{mp}) - aV_T I_{mp}} \tag{8}$$

RESULT AND DISCUSSION

This experiment was carried out at ambient temperature and reach a surface temperature of PV at 33°C which is measured with shielding at intervals of < 5 minutes since resulted a dark current I-V curve at the low current output. Fig. 4 shows the measurement results.

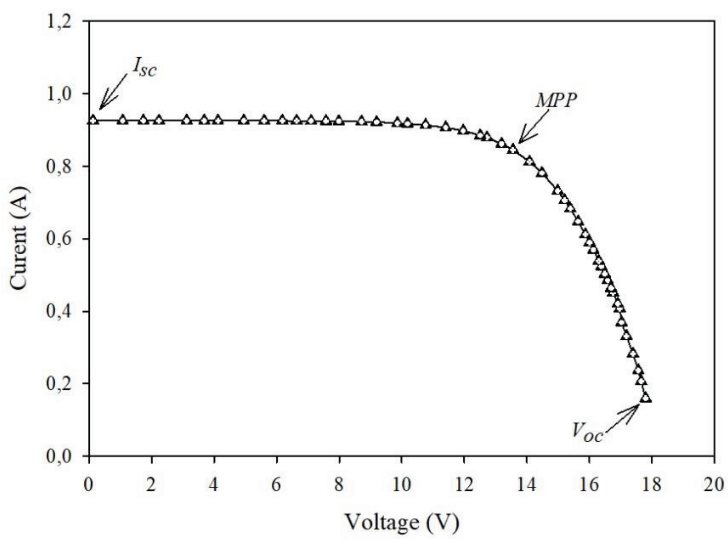

FIGURE 4. I-V curve of Hooray module I (V) curve with direct radiation

Important parameters for determining parasitic internal resistance are extracted from the I-V curve as shown in Tab. 2, while others parameter such as cell number is referred to the PV datasheet.

TABLE 2. Results of measurement parameters for curve I (V) and datasheet of PV module

No	Parameter	Symbol	Unit	Polycrystalline
1	Open circuit voltage	V_{oc}	V	16.9
2	Short circuit current	I_{sc}	A	0.93
3	Voltage in point Pmax	V_{mp}	V	14.08
4	Current in point Pmax	I_{mp}	A	0.82
5	Ideal diode factor	a	-	2
6	Cell number	n	-	36
7	Cell temperature	T	K	306
8	Thermal voltage	V_T	V	0.95

The Lambert-W function ($W_{(-1)}$) states that W (x) ≤ -1, the value of the Lambert-W (W (x)) and the constants in Equation (7) are calculated using the Mathlab and Mathcad software as shown in Tab. 3.

TABLE 3. Coefficients and functions of Lambert-W equation R_s

Constant	Value
A	2.184
B	-0.90
C	-6.05
D	-1.95
W(x)	-6.8390

The internal resistance values are calculated based on the obtained data using equations (7) and (8) resulted the internal resistance values of R_s and R_{sh} shown in Tab. 4.

TABLE 4. The parasitic internal resistance of PV modules and comparative data

Parameter	Our work	Cubas [11]	Taciuc [10]
R_s (Ω)	1.5	0.162	0.275
R_{sh} (Ω)	107.5	331	260

The related experiment has been carried out by [11] using polycrystalline PV type MSP29AS-36EU and also similar to the studies on the calculation of PV module parameter obtained by Lambert W-function [10]. The resulting value also shows that the value of internal resistance Rs is smaller than the Rsh resistance based on the previous research. Using the obtained I-V curve coefficients, an illustration of the complete equivalent circuit of PV module solar cells is shown in Fig. 5.

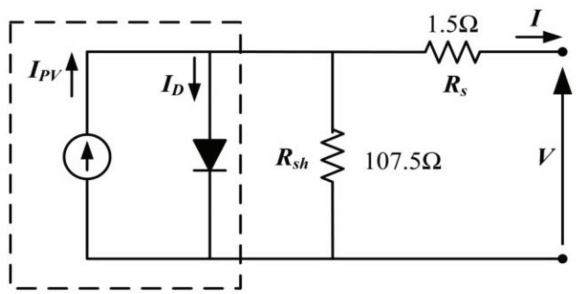

FIGURE 5. An equivalent circuit using internal parasitic resistance parameters R_s and R_{sh}

Internal characteristic of PV parameter will change and increase with time of operation, specifically the parasitic internal resistance due to direct sunlight and exposed to the rain and heat. The rise of internal resistance results a decrease in work ability characterized by a decrease in the output power of the PV module. The generated voltage remains constant, due to the increase in resistance value Rs and Rsh implies a decrease in PV current. Periodically observation of the parasitic internal resistance is needed so that the decline of the performance of PV modules can be estimated.

CONCLUSION

Determination of parasitic resistance of the Polycrystalline PV module using the Lambert-W function has been successfully implemented. Current voltage (I-V) curve is obtained by characterization of the Silicon Hooray MCP-2 with direct sunlight and resulted the V_{oc} and I_{sc} of 16.9 V and 0.93 A respectively. Lambert-W equation is used to determine the coefficient of parasitic series resistances R_s and R_{sh} at 1.5 Ω and 107.5 Ω which will change over a relatively long time interval during operation.

ACKNOWLEDGEMENTS

The authors acknowledge the Ministry of Research, Technology, and Higher Education of Indonesia for the funding through DIKTI Fundamental Research Program 2019 (No. 205/SP2H/LT/DRPM/2019).

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