International Electronic Journal of Pure and Applied Mathematics

Volume 10 No. 1 2016, 1-8
ISSN: 1314-0744
url: http://www.e.ijpam.eu
doi: http://dx.doi.org/10.12732/iejpam.v10i1.1

A METHODOLOGY FOR DETERMINATION OF SOME PHOTOVOLTAIC MODULE PARAMETERS

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Abstract: In the following article a methodology for estimation of some parameters and modeling of the characteristics of photovoltaic modules (panels) based on their data sheet parameters only is presented. A simplified and effective iterative procedure in Matlab was developed based on single-diode PV model for estimation of series (Rs) and shunt (Rsh) resistances of the equivalent electrical scheme. Finally, the $I-V$ and $P-V$ curves were obtained (simulated) and compared with the manufacture‘s data sheet.

AMS Subject Classification: 35Q60
Key Words: PV module, single-diode model, modeling, Matlab

1. Introduction

One of the most important points concerning the energy policy worldwide is the stable development and use of non-traditional and renewable energy sources to receive electrical energy [1]. Such an inexhaustible and free energy source is the sun. The sun energy doesn‘t render harmful influence to the environment and doesn‘t cause ecological problems in the process of its transformation to electrical energy (like prevailing un-renewable energy sources like carbon fuels). One of the ways to directly transform the sun energy into electrical is by using photoelectrical systems, built of photo elements – photovoltaic (PV) cells. PV cells are grouped in modules (panels), which are the basic structure units of PV energy sources and they are pro-

Received: August 14, 2015

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duced as single (individual) products. Usually every PV module consists of 36 to 72 PV cells. With the development of the PV technologies, the prices of PV systems‘ elements are decreasing and their effectiveness increases. The installed PV energy of PV power plants worldwide are increasing exponentially [1, 2].

This article presents a methodology for estimation of some PV module parameters and characteristics using only the manufactures ‘data sheet.

2. Determination of *Rs* and *Rsh*

For effective use of sun energy with PV systems reliable and precise enough models of PV modules are needed to achieve their $I-V$ and $P-V$ characteristics and to determine the maximum power point (MPP) [1,2,3,4]. This gives the opportunity to predict the behavior of designed PV installations in different values of sun radiation, temperature and loading. When modeling, equivalent electrical schemes are used – models of PV modules with a single diode and with two diodes [1,4,5,7,8]. The two-diode model gives better results when sun radiation is low (low voltages), but it has more parameters for estimation with long and complex iterative procedure [4,5,6,7,8].

A single-diode model was used in this article. The equivalent electrical scheme of the most often used single-diode model of PV module is shown at Figure 1 [2,3,4]. The photo element is shown as photo current generator *Iph* when it is irradiated with light; in the first approximation its electrical scheme can be modeled with a current generator and a diode, connected in parallel. Two resistors are included in the scheme – *Rs* is a serial resistor and it shows the resistance of every single PV cell and contact resistances; *Rsh* is a shunt resistor and it models all leakage currents as a result of structural and manufacturing diode defects, heat diffusion and carriers' recombination and other.

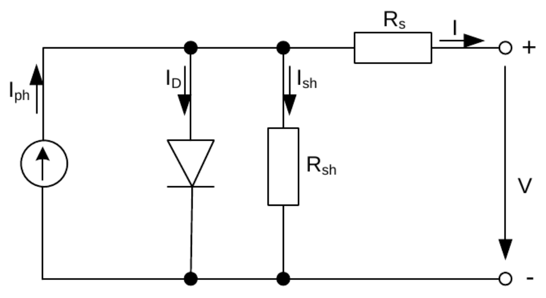

Figure 1: Equivalent electrical scheme of photovoltaic module

Volt-amper characteristics of the module, based on the scheme at Figure 1, can be described with the following basic equation:

$$I = I_{ph} - I_D - I_{sh}, \tag{1}$$

where

$$I_D = I_0 \left(\exp\left(\frac{(V + IR_s)q}{AkT} \right) - 1 \right), \quad I_{sh} = \frac{V + IR_s}{R_{sh}}, \quad V_t = \frac{N_s AkT}{q},$$

and I_{ph} – generated from the sun radiation current, I_0 – diode dark saturation current, V_t – thermal voltage of the PV array, k – Boltsman constant ($k = 1{,}38.10^{-23}$ J/K), q – electron charge ($q = 1{,}6.10^{-19}$ C), A – diode ideality factor, Ns – number of PV cells, connected in series, T – module temperature [K], I and V – module output current and voltage respectively.

In practice, it is important to determine the values of resistances Rs and Rsh based only on manufacture's data sheet in standard test conditions – standard sun radiation 1000 W/m^2, temperature 25^{o}C, sun spectrum Air Mass AM1,5. The following parameters are most commonly given by manufacture's data sheet: *Isc* (short circuit current), *Voc* (open current voltage), *Imax*, *Vmax*, *Pmax* and *Ns*. All these parameters are needed to model the module characteristics in different conditions and their effective usage.

Working in open circuit mode, the equation for generated photo current looks as:

$$I_{ph} = I_0 \exp\left(\frac{V_{oc} q}{N_s V_t} \right) + \frac{V_{oc}}{R_{sh}}. \tag{2}$$

Working in short current mode, the PV current is given by:

$$I_{sc} = I_{ph} - I_0 \exp\left(\frac{R_s I_{sc}}{N_s V_t} \right) - \frac{R_s I_{sc}}{R_{sh}}. \tag{3}$$

Substituting equation (2) in (3) gives:

$$I_{sc} = I_0 \left(\exp\left(\frac{V_{oc} q}{N_s V_t} \right) - \exp\left(\frac{R_s I_{sc}}{N_s V_t} \right) \right) + \frac{V_{oc} - R_s I_{sc}}{R_{sh}}. \tag{4}$$

The value of the second exponential function in equation (4) is times less compared to the first one [2,5], the equation (4) can be written as follows:

$$I_{sc} = I_0 \exp\left(\frac{V_{oc} q}{N_s V_t} \right) + \frac{V_{oc} - R_s I_{sc}}{R_{sh}}, \tag{5}$$

where the solution for dark saturation diode current I_0 will look as:

$$I_0 = \left(I_{sc} - \frac{V_{oc} - R_s I_{sc}}{R_{sh}} \right) \exp\left(\frac{-V_{oc} q}{N_s V_t} \right). \tag{6}$$

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Working in maximum power transmission mode, the PV current equation looks as:

$$I_{\max} = I_{ph} - I_0 \exp\left(\frac{V_{\max} + R_s I_{\max}}{N_s V_t}\right) - \frac{V_{\max} + R_s I_{\max}}{R_{sh}}. \tag{7}$$

Substituting equations (2) and (6) in (7), the equation for PV module current in MPT mode looks as follows:

$$I_{\max} = I_{sc} - \frac{V_{\max} + R_s I_{\max} - R_s I_{sc}}{R_{sh}} - \left(I_{sc} - \frac{V_{oc} - R_s I_{sc}}{R_{sh}}\right) \exp\left(\frac{V_{\max} + R_s I_{\max} - R_s I_{sc}}{N_s V_t}\right). \tag{8}$$

There are three unknown parameters in the last equation – diode ideality factor A (part of Vt) and resistances Rs and Rsh. The values of the two resistors are needed for completeness of the equivalent electrical scheme and optimal working mode determination (maximum power transmission to the load).

Some literature research shows that diode ideality factor for crystal modules (poly- and mono-crystalline) is 2 and less for amorphous silicon modules [2,3,5,6]. By experts opinion diode ideality factor is suggested to be chosen in the interval 1.2 – 1,6 and in this article the value of 1.3 was set.

Based on equation (8) the following dependence of Rsh was brought out:

$$R_{sh} = \frac{-V_{\max} + R_s I_{sc} - R_s I_{\max} + (V_{oc} - R_s I_{sc}) \exp\left(V_{\max} + R_s I_{\max} - V_{oc}\right)/(N_s V_t)}{I_{\max} - I_{sc} + I_{sc} \exp\left(V_{mpp} + R_s I_{\max} - V_{oc}\right)/(N_s V_t)}. \tag{9}$$

Differentiation of equation (8) and setting in maximum power transmission mode gives the following:

$$\left.\frac{dI}{dV}\right|_{I=I_{sc}} = -\frac{1}{R_{sh}}. \tag{10}$$

Based on equations (9) and (10) an iterative algorithm was developed (Figure 2) and procedure in Matlab to determine unknown resistors‘ values.

First, as inputs were set the module data sheet values (I_{sc}, V_{oc}, I_{mp}, V_{mp}, P_{max} and Ns) and all constants used in the equations. An initial value of Rs was given by equation (11):

$$Rso = \frac{Voc - Vmp}{Imp}. \tag{11}$$

Rsh was calculated by (9) and check for process convergence was made (12). Equation (12) is received from equation (10) and its left side consists of the derivative of module current against module voltage in short current mode; in the right side is the value that will terminate the iterative procedure [2]. If (12) is not fulfilled, Rs is decreasing with $\Delta R \quad = 1\ m\Omega$ and all calculations are repeated. If (12) is fulfilled,

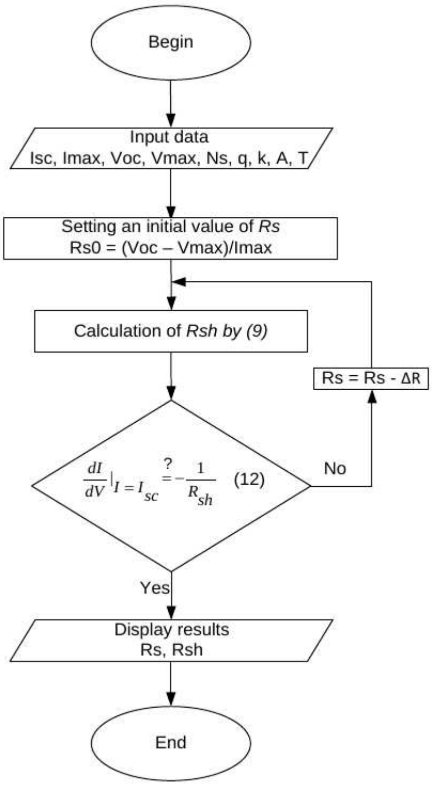

Figure 2: Block-scheme of iterative algorithm

iteration procedure is terminated and the values of two resistors Rs and Rsh are set as outputs.

$$\frac{-\dfrac{(R_{sh}I_{sc} - V_{oc} + R_sI_{sc})\exp((R_sI_{sc} - V_{oc})/(N_sV_t))}{N_sV_tR_{sh}} - \dfrac{1}{R_{sh}}}{1 + \dfrac{(R_{sh}I_{sc} - V_{oc} + R_sI_{sc})\exp((R_sI_{sc} - V_{oc})/(N_sV_t))}{N_sV_tR_{sh}} + \dfrac{R_s}{R_{sh}}} = -\frac{1}{R_{sh}}. \qquad (12)$$

In Table 1 different PV module data sheet (mono-crystalline, polycrystalline and thin-layer) and final results for Rs and Rsh are shown.

Using the final values or Rs and Rsh and software platform PVSYS different PV module $I - V$ and $P - V$ characteristics with MPP were obtained for different level of sun radiation (200, 400, 600, 800 and 1000 W/m^2) and PV work temperature (25, 50 and 75^{o}C). In Figure 3 and Figure 4 these characteristics are shown for two types PV modules – polycrystalline SP-PV120 (Figure 3) and thin-layer SP44 (Figure 4).

Module	SP-PV120	BP Solar MSX-60	Kyocera KG200GT	Shell S36	PVT 250 Wp	LX-10M	Shell SP-70	MAX50	MBX-3	SP44	Shell ST40
Type	Polycrystalline					Mono crystalline				Thin-layer	
Pmax [W]	135,2	60	200,143	36	250	10	70	50	195	44	40
Voc [V]	22,9	21,1	32,9	21,4	37,8	21,6	21,4	21,1	30,7	62,5	23,3
Vmax [V]	18,36	17,1	26,3	16,5	30,5	17,39	16,5	17,1	24,4	46	16,6
Isc [A]	7,86	3,8	8,21	2,3	8,75	0,64	4,7	3,17	8,6	1,26	2,68
Imax [A]	7,37	3,5	7,64	2,18	8,2	0,58	4,25	2,92	7,96	0,957	2,41
Ns [-]	36	36	54	36	60	36	36	36	50	36	36
Rs [Ω]	0,106	0,063	0,154	0,108	0,12	0,0172	0,303	0,1099	0,1515	0,15	1,1
Rsh [Ω]	343,12	175,97	425,13	285,5	400,64	766,8	98,806	258,71	183,4	158,77	126,19

Table 1: Block-scheme of iterative algorithm

3. Conclusion

A methodology for some PV parameters estimation and modeling of PV characteristics only using manufactures' data sheet is presented. Developed simplified iteration procedure in Matlab for estimation of PV module singe-diode model series and shunt resistances is described. $I-V$ and $P-V$ module characteristics were obtained for different types of PV modules – mono-crystalline, polycrystalline and thin-layer.

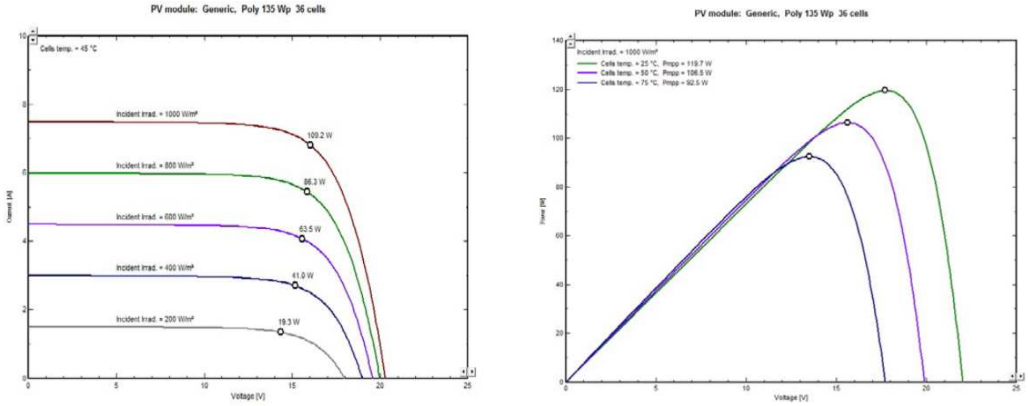

Figure 3: $I-V$ and $P-V$ characteristics for polycrystalline SP-PV120 PV module

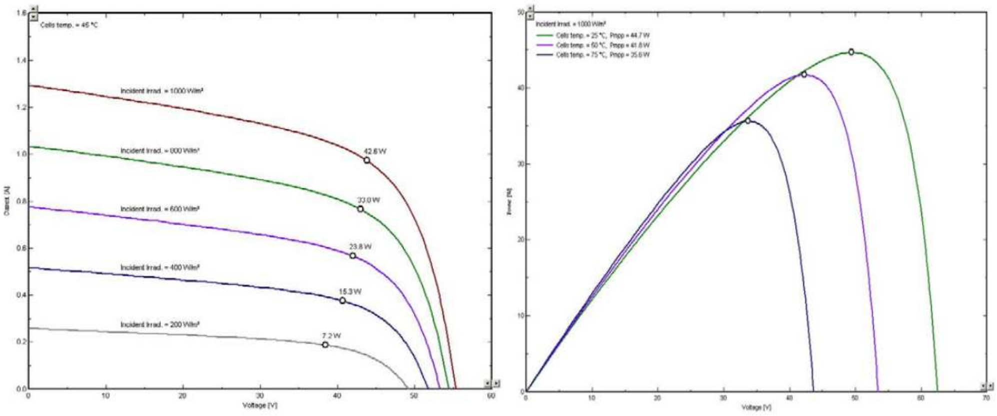

Figure 4: $I-V$ and $P-V$ characteristics for thin-layer SP44 PV module

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