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Estimation of the Parameters of a Photovoltaic Module from Manufacturer Data

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Abstract: In this study, an approach to determine the parameters of the equivalent circuit of a photovoltaic module and other parameters that are needed to determine the performance characteristics of the module is presented. The approach presented is based on the electrical parameters specified by the manufacturer of the photovoltaic module. To validate the approach presented in this study, the I-U characteristics of a photovoltaic module were computed by the proposed approach and the results were compared with those given by the manufacturer and almost, the 2 sets of results were identical. Also, a method to take the effect of the cell temperature on the I-U characteristics of the photovoltaic module is derived.

Key words: Photovoltaic, photovoltaic module, parameters, manufacturer data, temperature

INTRODUCTION

Photovoltaic arrays where solar radiation is converted into electrical energy are considered, as one of the important and clean renewable energy sources. The electrical energy produced from Photovoltaic (PV) arrays are used in several applications and several investigations have been conducted on using photovoltaic arrays in a lot of applications such as water pumping (Muljadi, 1997; Martins *et al*., 2000), lighting and power supply systems (Wu *et al*., 2000), grid-connected photovoltaic systems (Nayar *et al*., 2000; Giraud and Salameh, 2001; Iga *et al*., 2002; Shimizu *et al*., 2003), supplies for electric motors (Alghuwainem, 1996; Vongmanee *et al*., 2002) and other applications (Salameh and Lynch, 1990; Bahaj, 2000). In the analysis of many of the systems in which photovoltaic arrays are used, some parameters of the photovoltaic modules used in the analysis of the system have to be known, such as the resistance of the equivalent circuit of the module, the reverse saturation current and the photocurrent at Standard Test Conditions (STC). Usually, regarding the electrical characteristics of the PV module, only some of the electrical parameters are given by the manufacturer (Siemens Solar GmbH) and not all the parameters needed for the analysis of the system in which the photovoltaic modules are used. Several models of the photovoltaic module have been previously proposed by researchers (Chatterjee *et al*., 2011; Mahmoud *et al*., 2012; Tian *et al*., 2012; Siddiqui *et al*., 2013; Peng *et al*., 2014). However, these proposed models are either approximate or unduly lengthy. Therefore, the purpose of this study is to present a direct approach by which the resistance of the equivalent circuit, the reverse saturation current and the photocurrent of a photovoltaic module can be determined using the electrical parameters specified by the manufacturer of the photovoltaic module.

MATERIALS AND METHODS

A photovoltaic module is composed from a number of solar cells connected in series. The solar cell is a nonlinear device that can be represented by an equivalent circuit, such as that shown in Fig. 1 (Abdel-Halim *et al*., 1998).

The equivalent circuit consists of a current source (I_{ph}) which is the current produced when the sunlight falls on the cell and therefore, it is called the light-generated current or the photocurrent. The current source is in parallel with a diode that represents the p-n junction of the solar cell. The flow of current in the cell causes ohmic losses that can be represented by the resistance R_s. The equation describing the current-voltage (I-U) characteristics of solar cell is (Abdel-Halim *et al*., 1998):

$$U = -IR_s + (i/\Lambda)\text{In}\left[1 + \left(G.I_{ph} - I\right)\right]/I_o \quad (1)$$

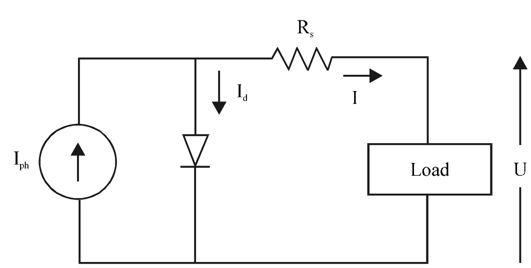

Fig. 1: Solar cell equivalent circuit

$$\Lambda = q/(mkT) \tag{2}$$

Where:

k = The Boltzmann constant (1.38×10^{-23} J K^{-1})
m = The a non-ideality factor whose value is usually close to unity (Markvart, 1995)
T = The absolute cell temperature
q = The absolute value of electron charge (1.602×10^{-19} C)
I_o = The cell reverse saturation current or the dark saturation current (Markvart, 1995)
G = The insolation (irradiance) level
I_{ph} = The cell photocurrent at an insolation level of 100% (G = 1.0)
$(1/\Lambda)$ = (mkT)/q is the thermal voltage of the solar cell (Chatterjee *et al*., 2011; Peng *et al*., 2014)

For a photovoltaic module consisting of (N_s) cells in series, Eq. 1 becomes:

$$U_g = -IR_sN_s + (N_s/\Lambda)\ln\left[1+\left(G.I_{ph}-I\right)/I_o\right] \tag{3}$$

Where:

U_g = The terminal voltage of the module
I = The current drawn from it

The electrical parameters of the photovoltaic module are specified by the manufacturer (Siemens Solar GmbH) under the standard test conditions which are: Irradiance (or insolation level):

- G = 1 kW m^{-2} (which corresponds to a 100% insolation level)
- Spectral distribution (or air mass) = AM 1.5
- Cell temperature = 25°C

These electrical parameters given by the manufacturer for the photovoltaic module are (Siemens Solar GmbH):

- Rated power (P_{max}) in Watt peak (Wp) which is the peak (or maximum) power of the module at standard test conditions
- Rated current (I_{MPP}) which is the current at maximum power point of the module
- Rated voltage (U_{MPP}) which is the voltage produced from the module at maximum power point
- Short-circuit current (I_{sc})
- Open-circuit voltage (U_{oc})

The electrical parameters of a photovoltaic module (SP75) manufactured by siemens solar (Siemens Solar GmbH) are used in this study and are given in Appendix as an example of the parameters specified by the manufacturer.

For an insolation level not equal that corresponding to the Standard Test Conditions (STC), the value of G in Eq. 3 has to be changed to take this into consideration. If, for example, the insolation level is 80%, the value of G in Eq. 3 becomes 0.8.

Determination of R_s, I_o and I_{ph}: In the following analysis it is assumed that the values of U_{oc}, I_{sc}, I_{MPP}, V_{MPP} and N_s are specified by the manufacturer and should be known in advance.

For a photovoltaic module the value of (Λ_{mod}) can be determined using Eq. 2 as:

$$\Lambda_{mod} = \Lambda/N_s = q/(N_s mkT) \tag{4}$$

At an insolation level of 100% and using Eq. 3 at open circuit with I = 0, the following relationship is obtained:

$$e^{\Lambda \text{ mod } Uoc} = \left[\left(I_{ph}/I_o\right)+1\right] \tag{5}$$

Thus:

$$I_{ph} = I_o\left(e^{\Lambda \text{ mod } Uoc}-1\right) \tag{6}$$

At short circuit with U_g = 0 into Eq. 3, I_{sc} is expressed by:

$$I_{sc} = \left[1/\left(\Lambda_{mod}N_sR_s\right)\right]\ln\left[\left(I_{ph}-I_{sc}\right)/I_o\right)+1\right] \tag{7}$$

From Eq. 6 and 7, the value of the reverse saturation current (I_o) can be derived as:

$$I_o = I_{sc}/\left(e^{\Lambda \text{ mod } Uoc} - e^{\Lambda \text{ mod } Isc\ Ns\ Rs}\right) \tag{8}$$

At maximum power point the voltage (U_{MPP}) is related to the current (I_{MPP}), using Eq. 3, by the relationship:

$$U_{MPP} = -I_{MPP}N_sR_s + \left(1/\Lambda_{mod}\right)\ln\left[1+\left(I_{ph}-I_{MPP}\right)/I_o\right] \tag{9}$$

Using Eq. 5 and 9, U_{MPP} is obtained as:

$$U_{MPP} = -I_{MPP}N_sR_s + \left(1/\Lambda_{mod}\right)\ln\left[e^{\Lambda \text{ mod } Uoc} - \left(I_{MPP}/I_o\right)\right] \tag{10}$$

Substituting from Eq. 8 into 10, a transcendental equation in the series resistance of the equivalent circuit of the cell, R_s is obtained as:

$$N_sR_s = -\left(U_{MPP}/I_{MPP}\right) + \left[1/\left(\Lambda_{mod}I_{MPP}\right)\right]\ln \begin{bmatrix} e^{\Lambda \text{ mod } Uoc} - \left(I_{MPP}/I_{sc}\right)e^{\Lambda \text{ mod } Uoc} + \\ \left(I_{MPP}/I_{sc}\right)e^{\Lambda \text{ mod } Isc\ Ns\ Rs} \end{bmatrix} \tag{11}$$

Equation 11 is a transcendental equation in the unknown (R_s) and can be solved numerically to get the value of R_s which is the cell series resistance.

The value of cell series resistance (R_s) obtained from the numerical solution of Eq. 11 is substituted into Eq. 8 to obtain the value of the cell reverse saturation current (I_o). This value of the current I_o is substituted in Eq. 6 to get the value of the photocurrent at standard test conditions (I_{ph}).

Thus, the values of the unknown parameters R_s, I_o and I_{ph} are determined.

Effect of cell temperature: At any insolation level, G to take the effect of the actual cell temperature, T_c, if it is not 25°C, the expression of the voltage of Eq. 3 becomes (Abdel-Halim *et al.*, 1998):

$$\begin{aligned} U_g = & -IR_sN_s + (N_s/\Lambda)\text{In}\left[1+(GI_{ph}-1)/I_o\right] \\ & -|V_{coeff}|N_s(T_C-25) \end{aligned} \quad (12)$$

Where, V_{coeff} is the temperature coefficient for the open-circuit voltage (dV_{oc}/dT) for each cell and it is negative and is given for a module in the manufacturer data sheets (Siemens Solar GmbH). The actual cell temperature, T_c is obtained from (Markvart, 1995):

$$T_c = T_a + (\text{NOCT} - 20)G/0.8 \quad (13)$$

Where, T_a is the ambient temperature and NOCT is the normal operating cell temperature measured under the following operating conditions at open circuit (Markvart, 1995):

- Insolation level = 0.8 kW m^{-2}
- Ambient temperature = 20°C and wind speed >1 m sec^{-1}

NOCT is usually given in the manufacturers data sheets of the solar module (Siemens Solar GmbH). For the solar module SP75 which consists of 36 cell and manufactured by Siemens solar (Siemens Solar GmbH) and whose parameters will be used in obtaining the results in the next section, the voltage coefficient V_{coeff} is -2.14 mV/°C for one cell and NOCT lies between 43°C and 47°C. The insolation level G in Eq. 13 is in kW/m^2. Thus, the effect of the cell temperature on the I-U characteristics of the photovoltaic module can be obtained.

RESULTS AND DISCUSSION

The method of analysis given in the previous section was used to obtain the values of R_s, I_o and I_{ph} of the solar module SP75 manufactured by Siemens solar (Siemens Solar GmbH) which consists of 36 solar cells and whose electrical parameters specified by the manufacturer are given in Appendix. The results obtained for this module when the proposed approach is used are:

$$R_s = 0.546\Omega, I_o = 3.07978063\times10^{-10}\text{ A and Iph} = 4.80\text{A}$$

The value of (Λ) of the cell was computed from Eq. 2 as:

$$\Lambda = 38.9358$$

Consequently the corresponding value of Λ_{mod} for the module is obtained as:

$$\Lambda_{mod} = \Lambda/N_s = 38.9358/36 = 1.0815488$$

To check the validity of the method presented in this study, the computed values of R_s, I_o and I_{ph} were substituted in Eq. 3 and the I-U characteristics of the module were computed at two insolation levels G = 100 and G = 80%. The obtained characteristics were compared with those given by the manufacturer (Siemens Solar GmbH), as shown in Fig. 2 for G = 100% and in Fig. 3 for G = 80%. From these comparisons, it is evident that the results obtained from the proposed approach are almost identical with those given by the manufacturer.

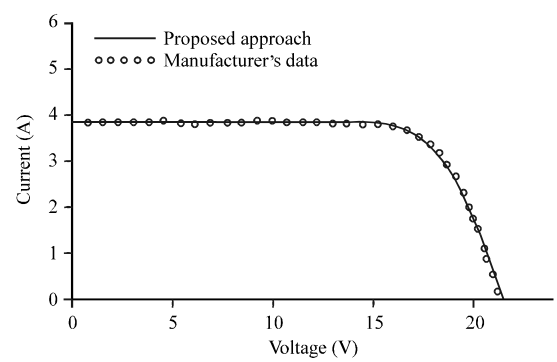

Fig. 2: I-U characteristic of the SP75 module at G = 100%

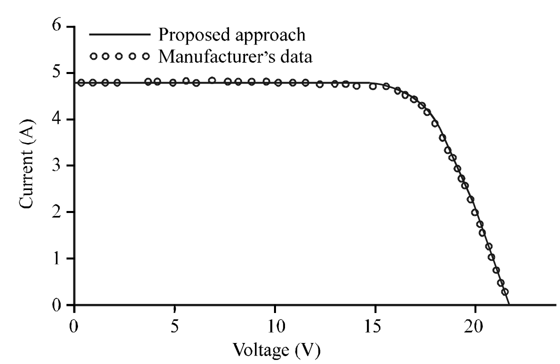

Fig. 3: I-U characteristic of the SP75 module at G = 80%

CONCLUSION

An approach was presented in this study to determine the parameters of a photovoltaic module, applying the data of the electrical parameters given by the manufacturer.

The computed I-U characteristics of a photovoltaic module, obtained at two insolation levels when the parameters obtained from this approach are used are almost identical with the characteristics given by the manufacturer.

Thus, this approach can be used to obtain the parameters of a photovoltaic array to perform the analysis of the system in which the module is used.

APPENDIX

The parameters given by the manufacturer for the SP75 photovoltaic module (Siemens Solar GmbH) for the 12 V configurations are:

Electrical parameters:
Maximum power rating P_{max} = 75 W_p (Watt peak)
Rated current I_{MPP} = 4.4 A
Rated voltage V_{MPP} = 17.0 V
Short-circuit current I_{SC} = 4.8 A
Open-circuit voltage V_{OC} = 21.7 V

Thermal parameters: Temperature coefficient for open-circuit voltage = -0.077 V/°C = -2.14 mV/°C for one cell
Normal Operating Cell Temperature (NOCT) = 45±2°C

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