A STUDY OF AN ANALYTICAL MODEL FOR A PHOTOVOLTAIC STATION

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Perfect modeling is essential to estimate the performance of PhV (Photovoltaic) modules in different environmental conditions. The comparison of the performance of solar cells with different models leads to the conclusion that the manufacturers did not provide the values of the resistance in series and parallel of the manufactured cell. Before installing a PhV system, a good performance estimation of the adopted PhV generators is essential since the initial cost of the system is pretty high. We may consider a generic solar cell whose illuminated I–V characteristics could be described by a lumped parameter equivalent circuit model consisting of a single exponential-type ideal junction, a constant photo-generated current source, a series parasitic resistance (Rs), and a parallel parasitic resistance (Rsh). Eventually, it is essential to take into account the condition of the maximum power point; knowing that the next steps of transformation to target was to attain the maximum power point.

Introduction

The PhV station usually consists of a number of PhV cells known as modules and usually are connected in series/parallel manner [1]. PhVcellsare made of a variety of semiconductor materials using different manufacturing processes [2].

The working principle of PV cells is essentially based on the PhV effect, which refers to the generation of a potential difference at the P-N junction in response to visible or other radiation. As a result, perfect modeling is essential to estimate the performance of PV modules in different environmental conditions, which have dramatic influence on Maximum Power Point control [3-5]. The comparison of the performance of solar cells with different models lead to the conclusion that that the manufacturers did not provide the values of the resistance in series and parallel of the manufactured cell.

The uses of these models are conditioned by the identification of the parameters of the equivalent circuits. Two main approaches are used to fulfill these tasks; analytical and numerical approaches [6, 7]. In fact, there are a number of their variation and combination. Although many more numerical solutions can be found in the literature [6] compared to those based on analytical reasoning [7]; this last approach is still used, especially when high degree of reliability is needed within the model recalculations (e.g., calculating the power supply in operational space-craft photovoltaic subsystems.

I. Simplification of the electric circuit model

The behavior of a solar cell, as a common approach, is usually modeled by a 1-diode and 2-resistor (1D-2R) electric circuit [6,7]; this simplest approximation gives satisfaction to the nature of the more important physical effects related to the photovoltaic conversion of the sunlight to voltage and current.

The authors in [8] mentioned that this model fits quite correctly the behavior of mono-crystalline and polycrystalline silicon cells at standard test conditions [7] and has certain deviation when conditions are not standard. It should also be fair to say that (1D-2R) model in recent years were considered as a simplification from the more accurate electric circuit model having 2-diode and 2-resistor (2D-2R).

The I-V characteristics of illuminated solar cells are customarily described by the use of a lumped parameter equivalent circuit, which requires considering the presence of parasitic series resistance and shunt resistance. The model parameters are closely related to the internal physical mechanisms acting within the solar cell. Their knowledge is therefore very crucial, first of all but not only for cell array and system simulation, but also for establishing an analysis tool to better understanding the processes involved and the influence of each parameter of the I-V characteristics [7,8].

II. Five parameters model

Consider a generic solar cell whose illuminated I–V characteristics can be described by a lumped parameter equivalent circuit model consisting of a single exponential type ideal junction, a constant photo-generated current source, a series parasitic resistance (Rs), and a parallel parasitic resistance (Rsh) presents the1D-2R model which is represented below in the form of equation [6]:

$$I = I_{pv} - I_D - I_{sh} \qquad (1)$$

Where;

I_{pv} is the photovoltaic current

I is the output current

I_D is the saturation current of the diode

I_{sh} is the shunt current through the resistor R_{sh}

The diode current I_D is expressed by the Shockley equation [9], which transforms (1) to algebraically well-known form as shown below

$$I = I_{pv} - I_0 [\exp A(V + IR_s) - 1] - \frac{(V+IRs)}{R_{sh}}, \qquad (2)$$

Where $A = \frac{q}{akT}$ which is considered as the photovoltaic cell parameters [6].

As it can be seen from (2), five parameters $\mathbf{I_{pv}}$, $\mathbf{I_0}$, $\mathbf{R_s}$, $\mathbf{R_{sh}}$ and ***a*** must be identified before calculation of the performance of the studied photovoltaic station.

The analytical approach is usually based on the data available from the data supplied by PhV suppliers; those normally are the most representative points: short circuit current: V=0, I=I_{sc}; open circuit voltage; V=$V_{oc}, I = 0$; maximum power; V=V_{mp}, and I=I_{mp} of the measured I-V curve of the solar cell (panel) [3].

Equation (2) can be written at three important manufacturer points through Standard Testing Conditions (STC) (i.e. short circuit (*SC*), open circuit voltage (*OC*) and maximum power point (*MPP*) as:

Short-circuit current: $I = I_{sc} = I_{pv}, V = 0$,

$$I_{sc} = I_{pv} - I_0 [exp[AR_sI_{sc}] - 1] - \left(\frac{R_sI_{sc}}{R_{sh}}\right) \qquad (3)$$

Open-circuit voltage: I=0, V=V_{oc}

$$0 = I_{pv} - I_0 [exp[AV_{oc}] - 1] - \frac{V_{oc}}{R_{sh}} \qquad (4)$$

Maximum power point: I=I_p , V= V_p

$$I_p = I_{pv} - I_0 [exp[A(V_p + R_sI_p)] - 1] - \frac{(V_p + R_sI_p)}{R_{sh}} \qquad (5)$$

It is important to find the values of the four unknown parameters I_{pv}, I_0 ,R_{sh}andR_s at various ideality factor values a. To simplify the calculations, several authors [3] recommend taking an ideality factor fixed value.

Using recommendation of [3,7], after several transformation we derived equations to find the photo current $I_{pv,}$the saturation current $I_0$and the shunt resistor R_{sh}.

$$I_{pv} = det^{-1}[[V_{oc}I_{sc}(\exp F) - 1] - [V_{oc}I_p(expG) - 1] - [V_pI_{sc}(\exp H) - 1]] \quad (6)$$

Where;

$$det = (V_{oc} - R_sI_{sc})[(\exp F) - 1] + \left(-V_{oc} + V_p + R_sI_p\right)[(\exp F) - 1] + (-V_p + R_s[I_{sc} - I_p]) [(\exp H) - 1] \quad (7)$$

Where F=A $(V_p + R_sI_p)$; G=A R_sI_{sc}; H=AV_{oc}

$$I_0 = det^{-1}(V_{oc}I_{sc} - V_{oc}I_p - V_pI_{sc}) \quad (8)$$

$$R_s{}^{-1} = det^{-1}[I_{sc}\,F - I_pG - \left(I_{sc} - I_p\right)H] \quad (9)$$

As a result, taking into account the condition of the maximum power point, then, the next steps of transformation are targeted to seek it.

In accordance with thedefinition of maximum power point: I=I_p , V= V_p which leads to

$$P_{max} = P_m = I_pV_p \quad (10)$$

MPP tracking performance is important to system designers who are guaranteeing a certain system performance and need to know all of the system parameters. The principle is to adjust the actual operating voltage V or current I of the PV array so that the actual power P approaches the optimum value P_{max}as closely as possible.

Finally taking into account the condition of the maximum power point, the next steps of transformation are targeted to proceed power point.

There are a number approaches [8-15], which will be considered.

Starting with the point that the power of a PhV is P=V*I for each point of the I-V characteristic the derivative of the power with respect to the voltage can be found

$$\frac{dP}{dv} = \frac{d\,(\mathrm{IV})}{d\mathrm{V}} = \mathrm{V}\frac{d\,\mathrm{I}}{d\mathrm{V}} + \mathrm{I} \quad (11)$$

Executing differentiation of (11) we will receive

$$\frac{dI}{dV} = -\left\lfloor R_s + \lfloor AI_0 \exp A\,(V + R_s\,I)\rfloor + R_{sh}{}^{-1}\right\rfloor^{-1} \quad (12)$$

Having in mind that the power of the PhV cell is P= I*V for every point of the I-V curve, the derivative of the power with respect to the voltage gives

$$\frac{dP}{dv} = \left(\frac{dI}{dv}\right)V + I \quad (13)$$

At the maximum power point of the P-V curve $\frac{dP}{dv}$ = 0, which brings (13) to

$$\frac{dI}{dv}\,\|\, p = p_{max} = -\frac{I}{V} \quad (14)$$

At maximum power point V=$Vmax$ and I =$Imax$ so the formula can be rewritten

$$\frac{dI}{dv} ⟦ p = p_{max} =- \frac{I_{max}}{V_{max}} =- \frac{I_p}{V_p} \tag{15}$$

$$\frac{dI}{dv} =- \frac{-aT - I_0 Rsh * expA(V + R_s I)}{aT(R_s + Rsh) + I_0 Rsh R_s * expA(V + R_s I)} \tag{16}$$

And by applying the proper substitution we will get;

$$\frac{I_p}{V_p} = - \frac{-aT - I_0 R_{sh} * \exp(A(V_p + R_s I_p))}{aT(R_s + Rsh) + I_0 Rsh R_s * \exp(A(V_p + R_s I_p))} \tag{17}$$

Considering general expression for power P=U*I and taking (17) into consideration

$$I_p = \mathrm{I}_{pv} - \mathrm{I}_0 \left[exp \left[A \left(\frac{dI}{dv_p} + R_s I_p \right) \right] - 1 \right] - \frac{(V_p + R_s I_p)}{R_{sh}} \tag{18}$$

with $I_p = I$ and V_p=V we can receive

$$P = V\left[\mathrm{I}_{pv} - \mathrm{I}_0 \left[exp[A(V \quad + R_s I \quad)] - 1\right] - \right] \text{-} \left(V \quad + R_s I_p\right)/R_{sh}]$$

$$= V\mathrm{I}_{pv} + V\mathrm{I}_0 \left(1 - \exp(PR_s + V ** 2)\right) \tag{19}$$

Taking derivation with respect to the voltage this will lead to:

$$\frac{dP}{dv} = V * aT(I_0 R_{sh} + I_{pv} R_{sh} - 2V) + I_0 R_{sh} (\exp(\frac{PR_s + V**2}{VaT}))$$

$$\lfloor PR_s - V(aT + V) \rfloor / V \left[I_0 R_1 \exp\left(\frac{PR_s + V**2}{VaT} \right) + aTR_{ss} \quad \right] \tag{20}$$

In (20) $R_1 = R_s R_{sh}$;R_{ss}=$R_s + R_{sh}$

It is necessary to point out, that at maximum power point (MPP)

$V = V_p$and $I \quad = I_p$, which brings to

$$\frac{dP}{dv} = 0 \tag{21}$$

Substituting (21) to (20) would lead to get the following;

$$V_p * aT\left(I_0 R_{sh} + I_{pv} R_{sh}\right) - 2V_p) + I_0 R_{sh} (\exp(\frac{V_p I_P R_s + V_p ** 2}{V_p aT}))$$

$$\left\lfloor V_p I_P R_s - V_p\left(aT + V_p\right) \right\rfloor / V_p \left[I_0 R_1 \exp\left(\frac{PR_s + V_p**2}{V_p aT} \right) + aTR_{ss} \quad \right] = 0, \tag{22}$$

Where; R_{ss}=$R_s + R_{sh}$

III. Conclusion

This paper stressed out the analytical expressions to determine the appropriate parameters of the PhV cell and those were derived accordingly. Knowing that the logical solution for each variable current and voltage as an explicit function of the other and of the device model parameters can be sought through the use of what is known as the Lambert "W" function, which is not expressible in terms of elementary analytical functions.

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