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A Simple Theoretical Method for the Estimation of Dynamic Resistance in Photovoltaic Panels

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ABSTRACT

In this paper, we propose a simple method to determine the dynamic resistance of a PV panel directly from a current-voltage (I-V) characteristic. The information currently provided in PV panel's datasheet by manufacturers is in general insufficient to construct a mathematical model. The dynamic resistance of the PV panel is determined by simple equations and a series of experiments including simulations and field data tests. Experimental results show that the resistance-estimation method allows exact prediction of the maximum power point under various weather conditions.

General Terms

PV Panel, Dynamic Resistance of the PV, MPPT Controller, Resistance-Estimation, Characteristics of PV Modules.

Keywords

Resistance-Estimation, MPPT (Maximum Power Point Tracking), PV Generator, Dynamic Resistance.

1. INTRODUCTION

For practical purposes it can be assumed that the power delivered by a photovoltaic generator that is connected to an MPPT is always the highest. If it is wished to study the behavior of a PV generator in that situation, the most interesting aspect is to know the evolution of the maximum power point. Then, the analysis of the characteristic I-V will focus on the part where voltages are high. From a simulation point of view this detail is important, because it must be ensured that the response of the model in that area is optimal. Firstly, because most times the results have a high degree of consistency with experimental data [1–3] and secondly, as they are not too complex it is relatively simple to implement and analyze them. The purpose of this paper is to present a simple procedure, based on simplified equations, which will allow the loss resistances of any crystalline silicon module to be estimated. The data required for calculations are those appear in any catalogue of modules (I_{SC}, I_{MP}, V_{OC} and V_{MP}). Although equivalent data obtained through test can also be used. Once the values of loss resistances are known, it is possible to trace the I-V curve with great accuracy. In all the cases studied the difference between the manufacturer's data and the results of the simulations was always less than 0.5%. Focusing on the resistance effect of the solar cells, we propose a new and simple method to directly determine the dynamic resistance of the PV modules from one point on an irradiated current voltage characteristic curve. This method is developed based on the p-n junction semiconductor theory of solar cells. Through [3] the direct resistance-estimation method will be discussed in detail in the following sections.

2. MODEL AND EQUATIONS USED

The PV panel model is based on the recombination mechanism of p-n junctions. The I-V characteristic of the PV modules is extremely nonlinear and varies significantly with temperature and solar irradiation. These disturbances affect the normal operation of the PV panels and may lead to a tracking of incorrect maximum power point which gives the necessity for the development of an accurate mathematical model. The equivalent circuit of a PV cell is shown is shown in Fig.1.

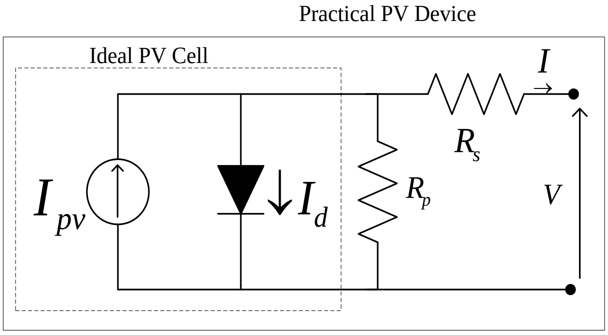

Fig.1 .The equivalent circuit of the Practical photovoltaic cell.

Using the developed method to directly estimate the dynamic resistance of the PV modules, we can control the MPP and achieve the maximum utilization efficiency of the PV modules. Fig. 1 shows the equivalent circuit for the PV modules.

$$I = I_{pv} - I_0\left\{\exp\left[\frac{V + R_s I}{V_T A}\right] - 1\right\} - \frac{V + R_s I}{R_p} \quad (1)$$

Where I_{pv} and I_0 are the photovoltaic and saturation currents of the array and $\mathbf{V_T = N_s kT/q}$ is the thermal voltage of the array with N_s cells connected in series. Cells connected in parallel increase the current and cells connected in series provide greater output voltages. If the array is composed of N_p parallel connections of cells the photovoltaic and saturation currents may be expressed as: $I_{pv}=I_{pv,cell}N_p$, $I_0=I_{0,cell}N_p$. In equation (1) R_s is the equivalent series resistance of the array and R_p is the equivalent parallel resistance. This equation originates the I-V curve seen in Fig. 2.

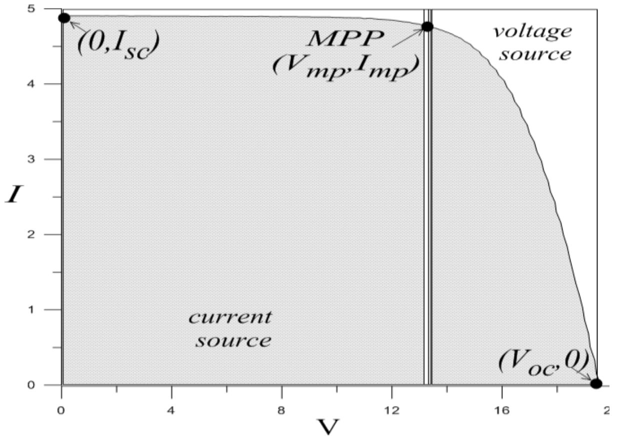

Fig. 2. Characteristic I-V curve of a practical photovoltaic: short circuit (0, Isc), maximum power point (Vmp, Imp) and open-circuit (Voc, 0).

depends on the internal characteristics of the device (R_s, R_p) and on external influences such as irradiation level and temperature. The amount of incident light directly affects the generation of charge carriers and consequently the current generated by the device.

The current (I_{pv}) of the elementary cells, without the influence of the series and parallel resistances, is difficult to determine. Datasheets only inform the nominal short-circuit current ($I_{sc,n}$), which is the maximum current available at the terminals of the practical device. The assumption $I_{sc} \approx I_{pv}$ is generally used in photovoltaic models because in practical devices the series resistance is low and the parallel resistance is high. The light generated current of the photovoltaic cell depends linearly on the solar irradiation and is also influenced by the temperature according to the following equation [5-7]:

$$I_{pv} = \left(I_{pv,n} + K_I \Delta T\right) \frac{G}{G_n} \qquad (2)$$

Where $I_{pv,n}$ [A] is the light-generated current at the nominal condition (usually 25 ◦C and 1000W/m2), $\Delta T = T - T_n$ (being T and T_n the actual and nominal temperatures [K]), G [W/m2] is the irradiation on the device surface, and G_n is the nominal irradiation. The diode saturation current I_0 and its dependence on the temperature may be expressed by (3):

$$I_0 = I_{o,n} \left(\frac{T_n}{T}\right)^3 \exp\left[\frac{qE_g}{Ak}\left(\frac{1}{T_n} - \frac{1}{T}\right)\right] \qquad (3)$$

Where Eg is the band-gap energy of the semiconductor (Eg ≈1.12 eV for the polycrystalline Si at 25 °C), and I_0,n is the nominal saturation current according to the following equation:

$$I_{0,n} = \frac{I_{sc,n}}{\exp\left(\dfrac{V_{oc,n}}{AV_{T,n}}\right) - 1} \qquad (4)$$

3. THEORETICAL ANALYSIS

A. Adjusting the model:

The purpose of the following analysis is the determination of the unknowns present in equation (1) by adjusting the PV model. The determination of these unknown parameters by an accurate mathematical formula may be useful for the prediction of the maximum power point, but such expression will be always dependent with the measured experimental data. An existing method is based on the variation of both Rs and Rp and the visual inspection for the fitting of theoretical and the practical I-V curves. But such approach gives inaccurate values for the resistances because the series and the parallel resistances are adjusted separately [6,8]. The relation between the unknowns of the equation (1) may be determined by setting Pmax,m=Pmax,e and then solving the resulting equation for Rp as the following equations show.

$$P_{\max,m} = V_{mp}\left\{I_{pv} - I_0\left[\exp\left(\frac{q}{kT}\frac{V_{mp} + R_s I_{mp}}{AN_s}\right) - 1\right] - \frac{V_{mp} + R_s I_{mp}}{R_p}\right\} = P_{\max,e} \qquad (5)$$

$$R_p = V_{mp}\left(V_{mp} + I_{mp}R_s\right)/_{mp}\, I_{pv} - V_{mp} I_0 \exp\left[\frac{\left(V_{mp} + I_{mp}R_s\right)}{AN_s}\frac{q}{kT}\right] + V_{mp} I_0 - P_{\max,e} \qquad (6)$$

B. Determining Rs and Rp resistance by iterative solution:

In the iterative process Rs must be slowly incremented starting from Rs = 0. Adjusting the P-V curve to match the experimental data requires finding the curve for several values of Rs and Rp. Actually plotting the curve is not necessary, as only the peak power value is required. Figs. 4 illustrate how this iterative process works as Rs increases the P-V curve moves to the left and the peak power ($P_{\max,m}$) goes towards the experimental MPP, and shows the contour drawn by the peaks of the power curves for several values of Rs (this example uses the parameters of the ISOFOTON I-75 Watts solar array).

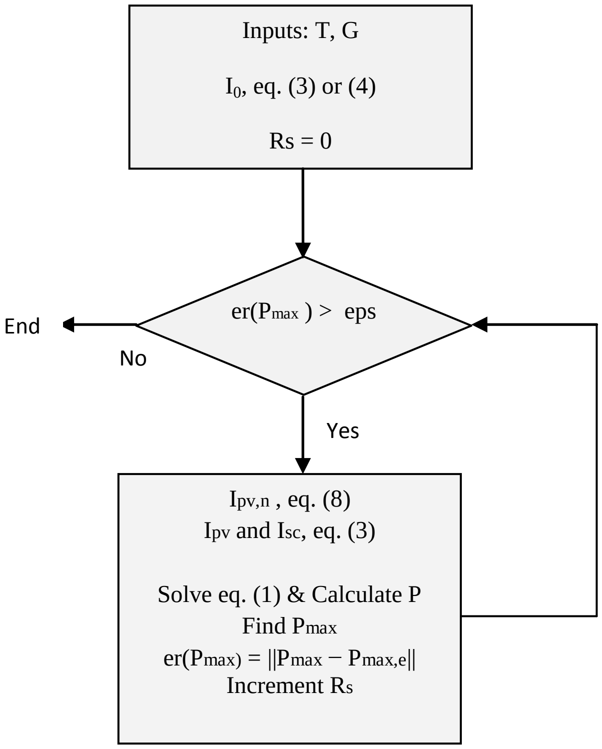

Fig. 5. Algorithm of the method used to adjust the I-V model.

The model developed in the preceding sections may be further improved by taking advantage of the iterative solution of Rs and Rp. Each iteration updates Rs and Rp towards the best model solution, so equation (7) may be introduced in the model.

The validity of the model with this new equation has been tested through computer simulation and through comparison with experimental data [10,11,12].

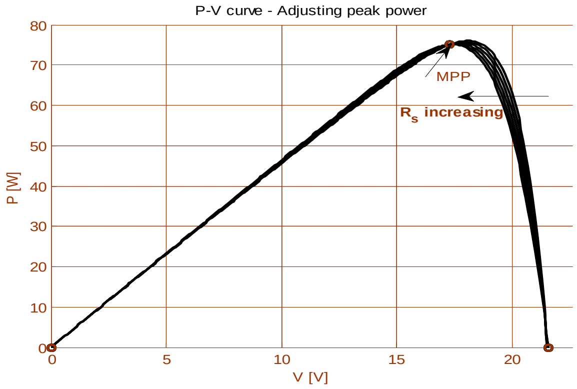

Fig.4. P-V curves plotted for different values of Rs and Rp.

TABLE I : Parameters of the ISOFOTON I-75 solar array at 25 °C, 1.5AM, 1000W/m2.

Imp	4.34 A
Vmp	17,3 V
Pmax,e	75.0820 W
I_{SC}	4.67 A
Voc	21.6 V
K_V	-0.01214 V/K
K_I	0.0032 A/K
Ns	36

$$I_{pv,n} = \frac{R_p + R_s}{R_p} I_{sc,n} \tag{7}$$

Eq. (7) uses the resistances Rs and Rp to determine Ipv = Isc. The values of Rs and Rp are initially unknown but as the solution of the algorithm is refined along successive iterations the values of Rs and Rp tend to the best solution and (7) becomes valid and effectively determines the light-generated current Ipv taking in account the influence of the series and parallel resistances of the array. Initial guesses for Rs and Rp are necessary before the iterative process starts. The initial value of Rs may be zero. The initial value of Rp may be given by:

$$R_{p,\min} = \frac{V_{mp}}{I_{sc,n} - I_{mp}} - \frac{V_{oc,n} - V_{mp}}{I_{mp}} \tag{8}$$

Eq. (8) determines the minimum value of Rp, which is the slope of the line segment between the short-circuit and the maximum-power remarkable points. Although Rp is still unknown, it surely is greater than Rp,min and this is a good initial guess.

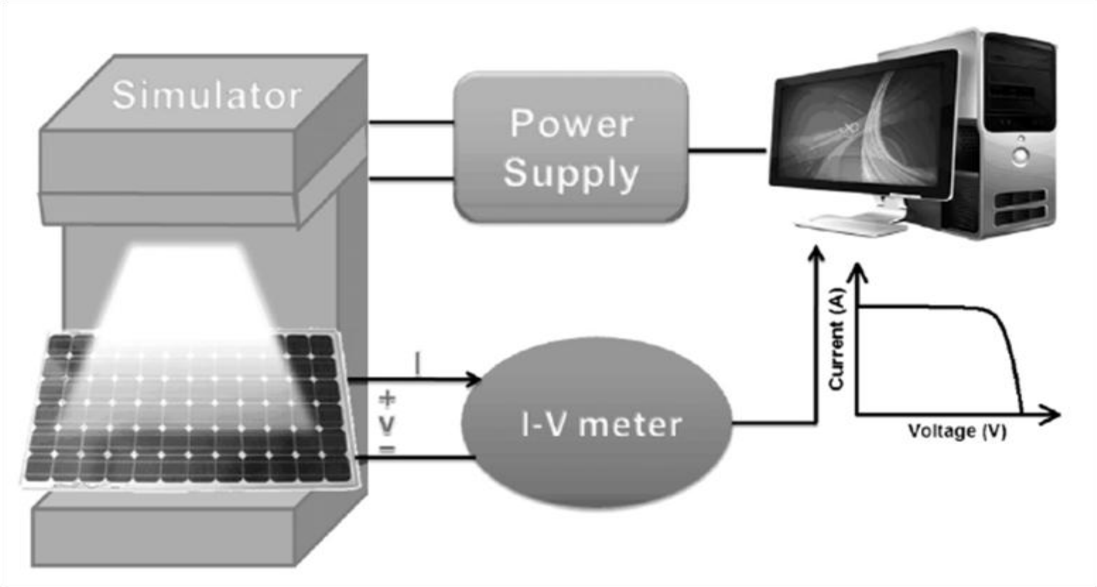

Fig. 6.A schematic diagram of the field data tests for the temperature-dependent and irradiation Intensity-dependent characteristics of the PV modules.

4. EXPERIMENTAL PROCEDURES:

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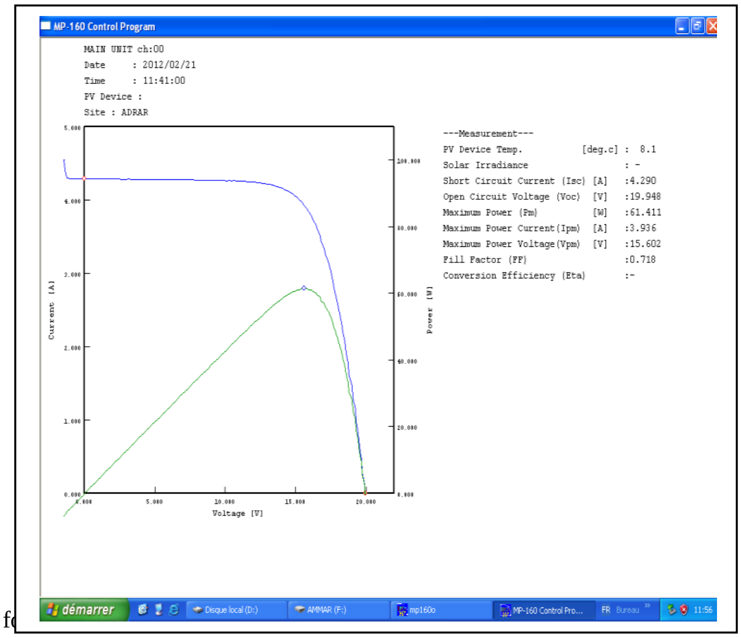

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MAIN UNIT ch:00
Date      : 2012/02/21
Time      : 11:41:00
PV Device :
Site : ADRAR

---Measurement---
PV Device Temp.                  [deg.c] :  8.1
Solar Irradiance                          : -
Short Circuit Current (Isc)  [A]   :4.290
Open Circuit Voltage (Voc)   [V]   :19.948
Maximum Power (Pm)           [W]   :61.411
Maximum Power Current(Ipm)   [A]   :3.936
Maximum Power Voltage(Vpm)   [V]   :15.602
Fill Factor (FF)                   :0.718
Conversion Efficiency (Eta)        :-
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To evaluate the performance of the proposed direct resistance estimation method, a variety of experiments including both numerical simulation and field tests with respect to PV modules composed many cell numbers, various irradiation intensities and temperatures were conducted in this work. In order to efficiently determine the dynamic resistance and achieve the impedance matching for any type or combination of PV modules, we used four PV modules composed of different cell numbers and examined the feasibility of the proposed direct resistance-estimation method [13,14].

The iterative method gives the solution Rs = 0.15 for the ISOFOTON I-75 array. There is an only point, corresponding to a single value of Rs, that satisfies the imposed condition $P_{max,m} = V_{mp}\ I_{mp}$ at the (V_{mp} ,I_{mp}) point. Fig.8 shows a plot of $P_{max,m}$ as a function of R_s and R_p for I = I_{mp} and V = $V_{mp.}$

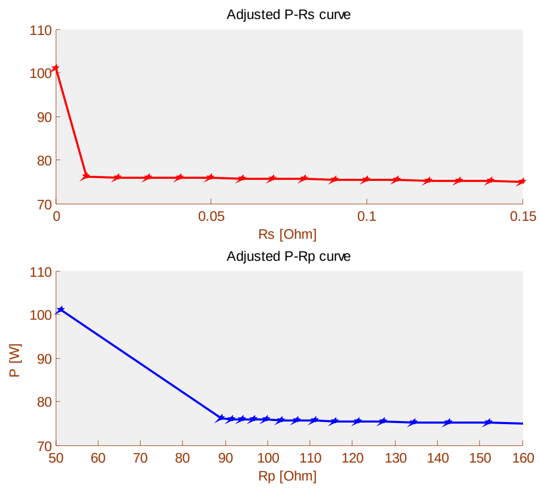

Fig. 8. $P_{max} = f(R_s)$, $P_{max} = f(R_s)$, **with** $I = I_{mp}$ **and** $V = V_{mp}$.

Table II: PARAMETERS OF THE ADJUSTED MODEL OF THE ISOFOTON I-75 SOLAR ARRAY AT NOMINAL OPERATING CONDITIONS.

ISOFOTON I-75W	P_{max} (V)	I_{sc} (A)	R_s (Ω)	R_p (Ω)
Experimental	75.082	4.67429	-	-
Simulation	75.007	4.67000	0.15000	163.59883
Differences	-0.0747	0.0043	-	-

The calculated dynamic resistance and the experimental values at the MPP of the PV modules are listed in Tables I and II for comparison. We can clearly see that in both cases the results are pretty similar. Using the proposed direct resistance-estimation method, the average percentage of prediction errors of dynamic resistances at the MPP of the PV modules under atmospheric conditions, respectively. The results indicate that the proposed method can achieve an accurate estimation of the dynamic resistance at the MPP of the PV modules under standard test condition & atmospheric the conditions. Figs. 9 illustrate how this iterative process works and the objective of adjusting the mathematical I–V curve at the three remarkable points was successfully achieved.

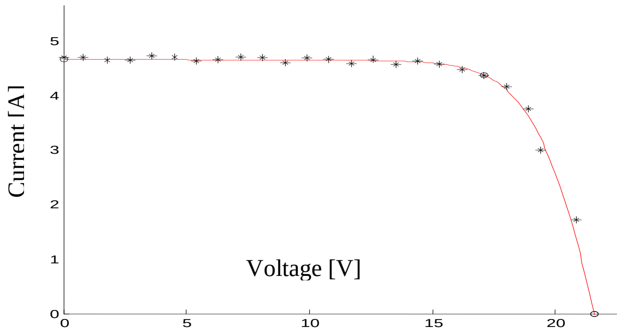

Fig. 9. Experimental data (points) and simulated I-V curve (solid line) of the ISOFOTON I-75 module.

such model is based on the determination of accurate values of the unknown parameters. The experimental results show the effectiveness of the proposed method for the determination of accurate values of the series and parallel resistances using simple expressions in the case of crystalline PV panels. The method can also be used to simulate I-V curves of different type of technologies (A-silicon, CIS, HIT, etc).

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