

Effect of Measurement Factors on Photovoltaic Cell Parameters Extracting

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ABSTRACT

In this paper, we study the influence of external factors on the measurement for the current–voltage (I-V) characteristic of the photovoltaic cell. These factors are the size of the number of measurements, the range of the cell generated voltage and the influence of measures step and mode combination of photovoltaic cells (parallel, serial, or hybrid). The main extracted parameters solar cell are the photocurrent I_{ph} , the reverse diode saturation current I_0 , the ideality factor of diode n , the series resistance R_s and the shunt resistance R_{sh} . A method for finding these parameters, according to the single-diode model, was developed by Newton-Raphson's method using Matlab. To assess the accuracy of this method, measured and calculated I-V characteristics were compared with provided data by the manufacturer at standard test condition (STC). The measurement results showed that these parameters are highly dependent on these four factors.

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1. INTRODUCTION

The photovoltaic solar energy is one of the most used and promising resources in the renewable energy domain. The conversion of photovoltaic energy is performed by cells based on semiconductors such as silicon, which exploits the photovoltaic effect. The operation of these cells is described generally by the I-V characteristic which provides the information on the mechanisms of intern electric transport and the technological steps imperfections of their fabrications [1], [2]. This characteristic depends on many intrinsic electrical parameters, that are the photocurrent I_{ph} , the saturation current I_0 , the ideality factor n , the R_s series and R_{sh} shunt resistances [3], [4].

The accuracy determination of these electrical parameters allows to understand and explain certain physical phenomena like the degradation of the layers that constitute the photovoltaic cells (PVC), the lifetime of minority charge carriers, the energy efficiency, ... etc. [5], [6]. Normally, several methods have been proposed for the extraction of these parameters using the single-diode model which is very sufficient to describe the electrical functioning of the cell [7], [8].

The purpose of this paper is to study the impact of extrinsic factors on the I-V characteristic measurements. That is, to study the influence of the size of the measurements basis, the distribution and the ranges of the output voltage of the solar cell and the types of the combination of the different cells that form

the solar modules. In general, these factors are often neglected by researchers in the field of electrical modeling and identification of the photovoltaic electrical parameters, especially in the phase of the I-V electrical characteristic measurements, which is the main source of electrical and physical information related to PVC [9], [10].

2. ELECTRICAL MODELING

The mathematical model that describes the photovoltaic cell is determined by that of PN junction. We add to it the photocurrent I_{ph} which is proportional to the irradiation and also a term that modulate electric intern phenomena. The given current I from the cell is written as follows [11].

$$I = I_{ph} - I_0 \left(\exp \left(\frac{V + R_s I}{n V_{th}} \right) - 1 \right) - \frac{V + R_s I}{R_{sh}} \quad (1)$$

with:

I_{ph} : Photocurrent current (or a generated current from irradiation).

I_0 : Diode saturation current.

R_s : Series resistance.

R_{sh} : Shunt resistance.

n : Ideality Factor of diode.

V_{th} : Thermal voltage given by $(V_{th} = \frac{k_B \cdot T}{q})$.

k_B : Boltzmann's constant ($k_B = 1.38 \times 10^{-23} \text{J} \cdot \text{K}^{-1}$).

q : Electrical charge of the electron ($q = 1.6 \times 10^{-19} \text{C}$).

T : Temperature of the cell expressed by °K.

Under illumination, a solar cell can be modulated by the electrical circuit with a single diode, represented in the Figure 1 [12]:

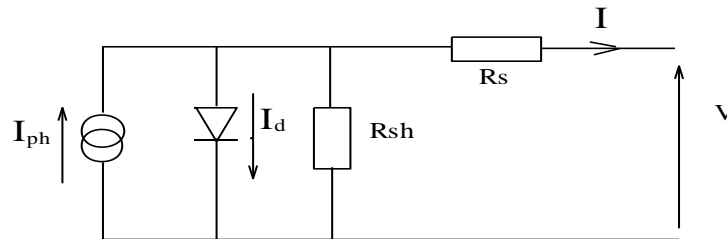


Figure 1. Equivalent Electric Circuit of a PVC

3. IDENTIFICATION OF PVC PARAMETERS

In order to understand the physical mechanisms produced within the interior of the solar cell; there are various parameters that specify these phenomena. Many methods have been proposed for the identification of these parameters, not only for increasing the efficiency of the photovoltaic cell, but also to be able to simulate its compartment and optimize their different parameters.

In our work, we use the model of a single exponential of the PN junction for the PV cell; formulated in the equation (1). This model depends on five electrical parameters such as, the photocurrent (I_{ph}), the reverse saturation current of diode (I_0), the series resistance (R_s), the shunt resistance (R_{sh}) and the ideality factor (n).

The most used methods to extract electrical parameters are:

- The method of least square [13].
- Newton's method [14].
- The Levenberg Marquardt's method [15].

The identification method that we use is based on the Newton's algorithm to find the final values of these parameters. This algorithm does not normally converge when the initial parameters (R_s , R_{sh} , I_{ph} , I_0 and n) are not well chosen. Indeed, to estimate these parameters, we used the bouzid's method [16] at the beginning of this algorithm.

Newton's method use an algorithm which search for the approximations of the roots of function $f(x)=0$. This method developpe the I-V model using Taylor's formula in the order 1 around an optimal point $f(V,I) = 0$ as the following expression:

$$f(I,V)=I-I_{ph}+I_0 \left(\exp \left(\frac{V+R_s I}{nV_{th}} \right) -1 \right) + \frac{V+R_s I}{R_{sh}} \quad (2)$$

For a given voltage V the current I is given by the root of equation (2), where "I" is expected to be the single root. In order to determine it, we start with the initial value I_i , the following iteration is executed:

$$I_{i+1}=I_i-f(I_i)/f'(I_i) \quad (3)$$

The iteration stops if a suitable condition is met. In the case above the absolute difference of two succeeding values of the iteration is used :

$$|I_{i+1}-I_i| < \varepsilon \quad (4)$$

Using the fitting technique of an experimental curve with a theoretical curve modulating the equation (1), we are able to determine intrinsic parameters of a solar cell. This technique focuses on minimizing the sum of the squares of the errors used in the objective function , defined as:

$$\chi(\varphi) = \sum_{i=1}^N (I_i^{exp} - I_i(V_i, \varphi))^2 = \sum_{i=1}^N R_i^2(\varphi) \quad (5)$$

- φ is a number of unknown parameters: $\varphi(I_{ph}, I_0, n, R_s, R_{sh})$
- R_i is a Residual error between experimental values I_i^{exp} and calculated values $I_i(V_i, \varphi)$.
- N is a Number of the measurement points.
- I_i and V_i are respectively the measured current and voltage at the N^i point of measured data.

We have used Newton's algorithm for the minimization of the objective function χ . The five optimal values of the parameters φ are evaluated by Newton's iterations:

$$\varphi_j = \varphi_{j-1} - [J(\varphi_{j-1})]^{-1} f(\varphi_{j-1}) \quad (6)$$

$J(\varphi)$: Jacobian matrix and their elements are defined as the derivatives of the current concerning the five parameters mentioned before $\left(\frac{\partial I}{\partial \varphi} \right)_{\varphi=\varphi_i}$

4. MEASURES AND USED TECHNIQUES

4.1. Experimental assembly

The measuring device comprises an electronic card based on a microcontroller (Arduino μC), a PC computer and an interface electronic card connected to the PV module. The computer is equipped with the LabView software for acquisition of current I and voltage V of the module through the Arduino analog inputs A0 and A1. Electromechanical relays are controlled by the μC , and allow changing PV load through binary / decimal decoders.

Measurement voltage V of PVC is performed by a voltage divider created by resistors, and operational amplifiers which provide impedance matching. In general, the maximum voltage at the output of the PV module is about 20 volts, so we use a ratio of $1/4$ to the voltage divider to get the maximum 5 volts on the analog input of μC .

To increase the accuracy of the measurement of the current, an amplifier gain of 2 is adjusted and used at the output of this sensor. Electrical measurements are taken using an automatic solar tracker, which

we developed to ensure a relatively constant light intensity for these measures [16]. Figure 2 is shows used experimental assembly.

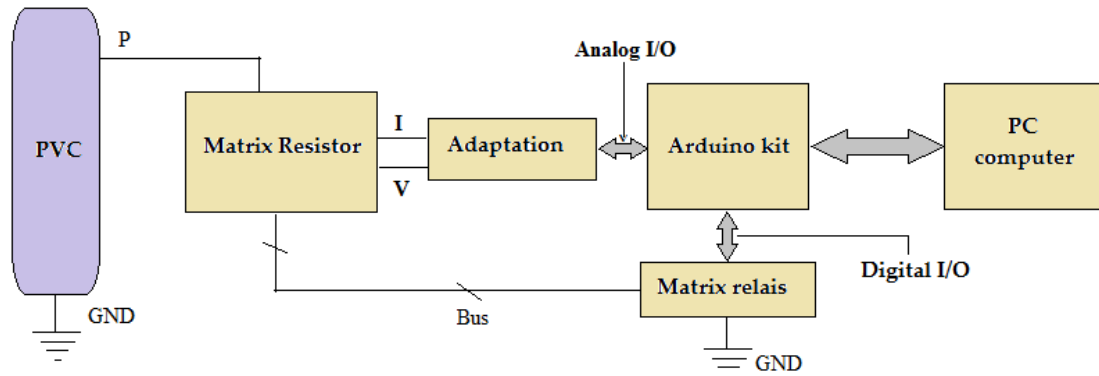


Figure 2. Used Experimental Assembly

4.2. Measurement technique

The test experiments realized are performed according to an assembly of measures achieved from solar panel constituted from silicon polycrystalline “Solarex MSX60”. This module is composed of 36 solar cells which are combined parallel at the Standard Test Condition STC of the irradiation and the temperature. Our research group has already worked on optimizing these measures by improving methods and instruments of the optimal measuring I-V of a solar panel [17].

This paper highlights the effects of the impact of the four major factors on the accuracy of the intrinsic parameters of the electric model (R_s , R_{sh} , I_{ph} , I_0 and ideality factor n). These factors are:

1. The size of the measured data base on the I-V characteristic, which means the number (N) of measurement points for measuring the I-V characteristics of solar cells. The number (N) of the measurements realized during the experience of I-V.
2. The nature and the values of the step of the measures (I_j , V_j) in a characteristic.
3. The distribution of the measures on the different zones of the voltage V of the characteristic. Three zones are precised; the zone 1, for low voltages, the zone 2 for medium voltages and the zone 3 is related to the high voltages.
4. The association of the connection of the PV cells in the interior of a PV module.

In our case, we have studied the effect of two types association of the cells. In the first side, the series association of two PVC is examined, followed by a test on another parallel association of the cells. The validation and the interpretation of the results discovered are made through a comparing between these values with a reference [17]. Taking into account that during the steps of these measures, we have respected the acquisition technique and the filtering without noise which is developed by our research group [10], [18]. After determining the optimal factors that give a better measure, a deep study is currently underway by our research group to determine the relation between of the minorities carriers lifetime of electrons and holes τ_n and τ_p respectively and intrinsic electrical parameters.

5. RESULTS AND DISCUSSION

Before studying the impact of these factors on the reliability and the accuracy of the PVC electrical parameters, the device and the developed program were tested and their results were compared with a mathematic model (equation 1). The simulation and measured results of I-V characteristics are compared and shown in Figure 3.

From the first sight, this curve provides an enough confidence on the tools of taken measures during this work. It is noted that, there is a correlation between the measured data and the electrical model of the single diode, within the whole range of the applied voltage which is changed from 0V to $V_{oc} = 21.1V$ in 40 measures data base. Indeed, to have more details about of the influence of measured numbers (N) and divided step (Δ) of these measures, tests are carried on the same photovoltaic cell by varying these two parameters.

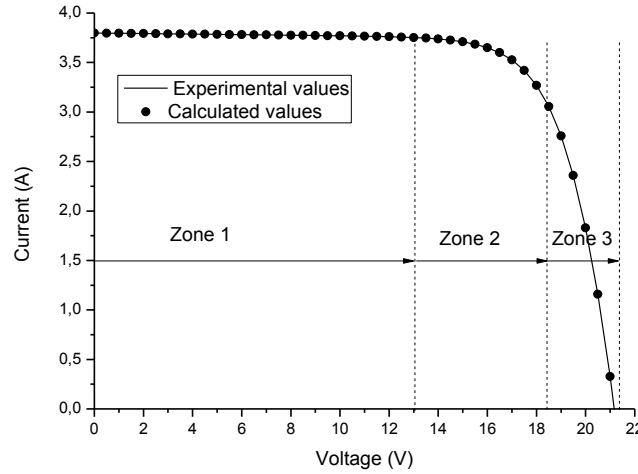


Figure 3. Experimental and Calculate of PVC Characteristics

5.1. Effect of the Measurements Number (N)

5.1.1. Measures with a Constant Step

A constant step of taken measures (I_j, V_j) are chosen in this level. The measurements were carried from the whole range of voltages $[0V - V_{oc}]$, through a step $\Delta = \frac{V_{oc}}{N}$ for each size of the measured data base. Electrical parameters are calculated by the developed program [16], and the results are shown in the Figure 4. The calculated error R as a function of the number of the measures (N) is presented in the Table 1.

Table 1. Measurement Error with Number (N)

N	20	40	60	90	110	150	160	180	200	220
$R(\times 10^{-6})$	0.67	0.06	8.7	2.2	0.63	2.8	11.5	10.4	3.52	2.0

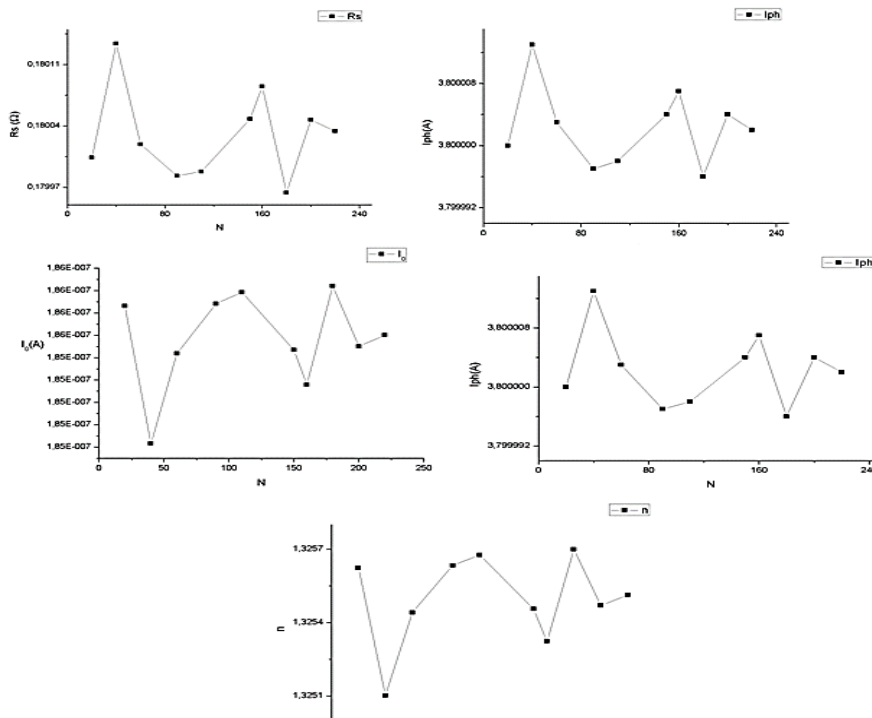


Figure 4. Variation of PVC Electrical Parameters with N

This table shows a minimum value of the error R which fits with a number $N = 40$ of measurements. The Figure 3 presents a minimum at $N = 40$ concerning the three parameters R_{sh} , I_0 and n , whereas the other parameters R_{sh} and I_{ph} , show a maximum at $N = 40$.

Meanwhile, this result guides us to minimize the number of I-V measurements, in order to save time and energy while measuring. Furthermore, it allows us to save the memory space for digital devices of acquisition. Indeed, in contrary to what we believe that a big number of measurements are frequently required. A reduced number of measurements is largely sufficient and it is sometimes optimal in order to discover specific results of the electrical parameters. This is explained by the reduction of the fluctuations and the minimization of the errors produced through a large data base of measurements. On the other hand, concerning the values (N) which are greater than 40, the accuracy of PVC electrical parameters are not linear. So, instead of using larger sizes of the measures of the I-V characteristic, we take a minimum number of measurement ($N = 40$) as in our case.

5.1.2. Measures with a variable step

The measuring of the I-V characteristic at this level was examined by taking a variable step (Δ). Indeed, the three zones have been fixed:

$\Delta_1 = 0.4$ V: Low voltages domain, as ($0 < V < 5/8 V_{oc}$),

$\Delta_2 = 0.01$ V: Medium voltages domain, as ($5/8 V_{oc} < V < 7/8 V_{oc}$),

$\Delta_3 = 0.2$ V: High voltages domain, as ($7/8 V_{oc} < V < V_{oc}$).

The electrical parameters extracting (R_s , R_{sh} , n , I_{ph} and I_0) are calculated and presented in Table 2.

Table 2. Comparison of the Intrinsic Parameters with the Variable and Constant Step

Electrical parameters	$R_s(\Omega)$	$R_{sh}(\Omega)$	$I_{ph}(A)$	$I_0(A)$	n
Variable step (Δ)	0.179	360.123	3.7999	1.85×10^{-7}	1.325
Constant step (Δ) = 0.5V	0.180	360.020	3.8000	1.85×10^{-7}	1.325
Reference [18]	0.180	360.002	3.8119	1.85×10^{-7}	1.360

From these values, it is found that the variation of the step (Δ) of the voltage does not have too much effect on the electrical parameters of the cell. Therefore, it is recommended to work with a regular step to optimize the electrical measurement chain. A variable step (Δ) requires additional time to the processor which rotates the calculation algorithm. Indeed, the program is slower and requires more storage space for the iterations. Therefore, the calculation is more complicated and makes the possibility of divergence of the program.

5.2. Effect of the bias voltage ranges:

We took the best measures which correspond to the 40 measures in Table 3.

Table 3. Intrinsic Electrical Parameters Depending on the Variable Voltage Range

Voltage Range (V)	$R_s(\Omega)$	$R_{sh}(\Omega)$	$I_{ph}(A)$	$I_0(A)$	n
Low [0-5/8Voc]	54.681	304.732	4.4796	1.04×10^{-108}	0.966
Averages [5/8Voc-7/8Voc]	1.895	27.681	4.4964	1.02×10^{-23}	0.504
High [7/8Voc -Voc]	0.330	0.534	40.1492	2.33×10^{-52}	0.193
Reference [18]	0.180	360.002	3.8119	1.85×10^{-7}	1.360

At a low voltage domain, the obtained electrical parameters show that the optimal parameters are those of R_{sh} , I_{ph} and n according to the output voltage ranges of the solar cell module. At a medium voltage domain, the optimal parameter is that the saturation current I_0 . At high values of voltage, the optimal value is that of the series resistance R_s .

5.3. Effect of PVC association:

The used photovoltaic cell in this work is that of silicon [17]. The effect of the mounting type of these solar cells was studied in the case of a series connection, and then in parallel. The results are shown in Table 4.

Table 4. Intrinsic Electrical Parameters Depending on the Type of Association

solar cell mounting	$R_s(\Omega)$	$R_{sh}(\Omega)$	$I_{ph}(A)$	$I_0(A)$	n
One cell	0.106	872.398	0.1023	6.30×10^{-8}	1.416
Two series of cells	0.213	1744.843	0.1023	6.30×10^{-8}	2.833
Two paralleled cells	0.038	503.329	0.2045	1.96×10^{-7}	1.460
Reference [18]	0.180	360.002	3.8119	1.85×10^{-7}	1.360

Based on the extracted values from the Newton's method, we found that in the case of a series connection, the electrical parameters R_s , R_{sh} and n having values that are doubled, contrary to the photocurrent I_{ph} and the saturation current I_0 remain unchanged. In the case of a parallel association, the parameter I_{ph} is doubled, contrary to the ideality factor n that remains constant and the saturation current I_0 are significantly increased, whereas the resistances R_s and R_{sh} are decreased in a low manner.

6. CONCLUSION

In this work, we have studied the sensitivity of the intrinsic electrical parameters of a photovoltaic solar cell (the photocurrent I_{ph} , the saturation current I_0 , the ideality factor n , the series resistance R_s and the shunt resistance R_{sh}) according, first, to the number of measures (N), second, to the step of the I-V characteristics voltages, third, to the range of voltages in this characteristic and the type of the different cells connection. So, the obtained electrical parameters are relatively depending on the previous factors. Based on what has preceded, we deduce that the minimum number of measurements ($N=40$ in our case) is largely sufficient and it is recommended to work with a regular step to optimize the accuracy of the extracted parameters. Relatively to the range of voltages, we must choose the low output voltages in order to achieve an optimal measure of the following parameters R_{sh} , I_{ph} and n . However, the optimal value of the extracted series resistance R_s must be made in high bias voltages; while the extracted saturation current I_0 should be performed in the average voltages. Concerning the influence of different cells connection mode, we observe that the values of electrical parameters R_s , R_{sh} and n , are approximately doubled in the PVC series combination; whereas, the photocurrent I_{ph} also doubled in a parallel association in this study. These last results are in accordance with the theoretical results, while the other results are unexpected and can be exploited to increase the performance of the PVC and their installations.

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