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STUDY OF THE EQUIVALENT CIRCUIT OF A DYE-SENSITIZED SOLAR CELLS

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ABSTRACT

The dye-sensitized solar cells (DSSC) have gained the last decades an important place among photovoltaic technologies due to their low-cost of implementation and their performance, which becomes more efficient. The experimental data for this type of cells are enriched and accumulated quickly, given the enthusiasm for this new technology. The present work treats the equivalent circuit of a dye-sensitized solar cell (DSSC) for a model in an exponential, and by using the results of some works, we shall make a simulation by the software Scilab to obtain the characteristics (I-V), then we will study the influence of every parameter on the curve.

Keywords

DSSC, Model, Characteristic I-V, Equivalent circuit

1. INTRODUCTION

Mathematical modelling of solar cells is essential for any operation yield optimization. In general, the photovoltaic module is represented by an equivalent circuit in which the parameters are calculated using the experimental current-voltage characteristic. These parameters are generally quantities neither measurable nor included in the data of the manufacturing. As a consequence, they must be determined from the systems of the equations *I-V* (Courant-tension) to diverse points of functioning given by the manufacturer or stemming from the direct measure on the module.

Modelling of the latter has emerged as a crucial step and has led to a diversification in the proposed models by different researchers. Their differences are situated mainly in the number of diodes, the resistance shunt finite or infinite, the factor of ideality ,constant or not, as well as the numerical methods used for the determination of the various unknown parameters.

2. ELECTRIC MODELS OF SOLAR CELLS

The modelling of the photovoltaic cells passes necessarily by a sensible choice of the equivalent electric circuits. To develop a precise equivalent circuit for a photovoltaic cell (*PV*), it is necessary to understand the physical configuration of the elements of the cell as well as the electric characteristics of each element, by taking more or less of details.

According to this philosophy, several mathematical models are developed [1]. These models differ between them by the mathematical procedures and the number of parameters involved in the calculation of the voltage and current of the photovoltaic module.

2.1. Model with a diode

The functioning of a photovoltaic module is described by the standard model for a diode. It is generalized to a PV module by considering it as a set of identical cells branched in series or in parallel. This model includes a diode. ("Fig. 1,")

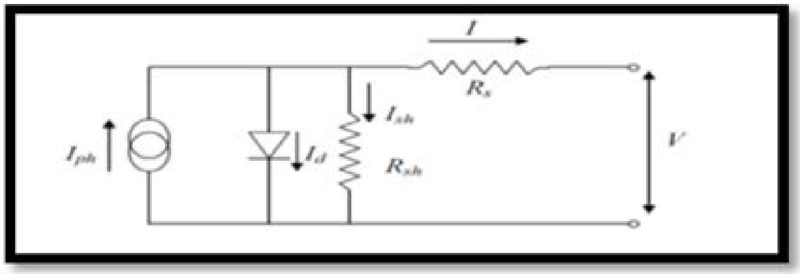

Figure 1. Equivalent circuit of a *PV* cell. Model for a diode.

The current supplied by the cell is given by the following relation:

$$I = -I_{ph} + \frac{V - R_S I}{R_{sh}} + I_s \left[\exp\left(\frac{q(V - R_S I)}{AkT} \right) - 1 \right] \qquad (1)$$

With:

I → Current supplied by the cell [A].
V → The terminal voltage of the cell [V].
I_{ph}→ The photo-current [A], which is proportional to the irradiance.
Is → Saturation current of diode [A], the temperature dependent.
R_s → Series resistance [Ohm].
R_{sh} → Shunt resistance (or parallel) [Ohm].
q → Electron charge = $1{,}602.10^{-19}$ Coulomb.
k → Boltzmann constant = $1{,}38.\ 10^{-23}$ J/K
A → Ideality factor of the diode.
T → Effective temperature of the cell [Kelvin].

2.2. Model with two diodes

We have, this time, two diodes, these diodes symbolize the recombination of the minority carriers, on one hand on surface of the material and on the other hand in the volume of the material [2]. The diagram of the equivalent circuit ("Fig. 2,") for a model in two diodes becomes:

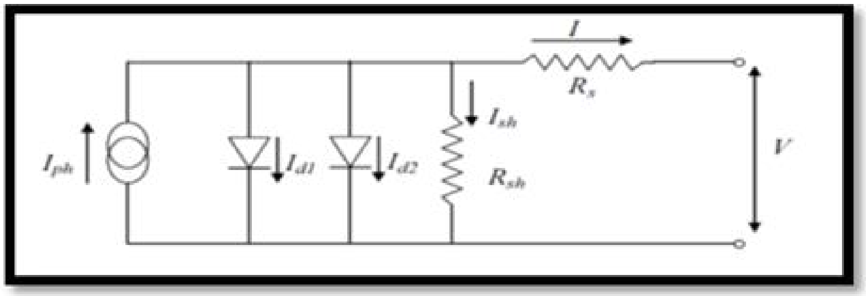

Figure 2. Equivalent circuit of a *PV* cell. A model with two diodes

The current supplied by the cell is given by the following relation :

$$I = -I_{ph} + \frac{V - R_s I}{R_{sh}} + I_{s_1}\left[\exp\left(\frac{q(V - R_s I)}{AkT}\right) - 1\right] + Rec \qquad (2)$$

With:

$$Rec = I_{s_2}\left[\exp\left(\frac{q(V - R_s I)}{2AkT}\right) - 1\right] \qquad (3)$$

The occurrence of the current of saturation results phenomena of recombination.

3. EQUIVALENT CIRCUIT OF A DYE-SENSITIZED SOLAR CELL

3.1. Equivalent Circuit

The model of an equivalent circuit of DSSC allows not only to obtain the network of cells and simulation of the system, but also it contributes to the analysis of the implied electric processes. Generally, a traditional model of equivalent circuit for the DSSC contains a single diode, a constant source of photo-generated current, series resistance (R_s) and a parallel resistance (R_{sh}). The diagram of the equivalent circuit is indicated on following figure:

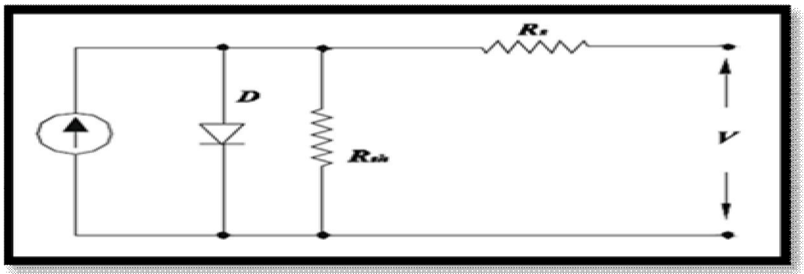

Figure 3. Equivalent circuit of a dye-sensitized solar cell

3.2. Parameters used

Several works were made concerning the estimation of the parameters of the cell from the equivalent circuit [3-4]. The experimental work of Masaki and Tatsuo [5] their allowed to deduct from the curve (*I*-*V*), the various parameters of simulations, which are summarized in table

Table 1. Various parameters of simulation calculated by Masaki and Tatsuo.

Parameters	I_{cc}	V_{co}	**n**	R_s	R_{sh}
Group 1	0.0024	0.699	2.5	38.1	3683
Group 2	0.00236819	0.69173	2.402	53.1	9959

4. RESULTS AND DISCUSSIONS

4.1. Method of resolution

The simulation is done through the Scilab software; it is free software for numerical computation providing a computing environment for scientific applications. Scilab possesses numerous pre-programmed functions and extended possibilities of graphic visualization. It can be used for signal processing, the statistical analysis, the image processing, the simulations of fluid dynamics, the numerical optimization, and the simulation and the modelling of explicit and implicit dynamic systems. Scilab can execute online instructions of command, as well as files of command line (scripts) containers of the instructions (text format). It can equally execute programs, Fortran or C from Scilab.

We divided our simulation program into 5 subprograms, each will depend on the values of the groups in the table 1. To get the characteristic *I-V*, the program is set up in the open-circuit condition with the equilibrium values, then the external resistance is varied.

4.2. Results

4.2.1. Characteristic *I-V*

With the equivalent circuit ("Fig. 3,") and using Kirchhoff's law, we obtain the following equations:

$$I_{ph} - I_{sh} - I_d = 0 \tag{4}$$

$$V_d = V_{sh} = V_s + V + I_s R_s + V \tag{5}$$

The current of the diode is given by the following formula:

$$I_d = I_0 \left(\exp\left(\frac{qV_d}{KTn} \right) - 1 \right) \tag{6}$$

The expression of the current is given by the following equation:

$$I = I_{ph} - \frac{V + R_s I}{R_{sh}} - I_0 \left[exp\left(\frac{q(V + R_s I)}{AkT} \right) - 1 \right] \tag{7}$$

<u>With:</u>

I_o → The initial current [A].
R_s → The serie resistance [Ohm].
R_{sh}→The shunt resistance [Ohm]
T →The temperature [K].

K →Boltzmann's constant [J/K]
q → The elementary charge [Coulomb].
n → The ideality factor.
I_{ph} → Photocurrent [A] ; I_d → Diode current [A]

By programming with Scilab, we obtained the following graphs:

Group 1:

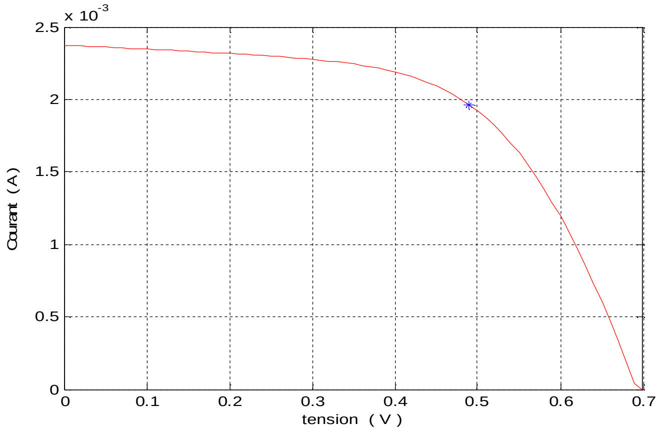

Figure 4. *I-V* characteristic of group 1.

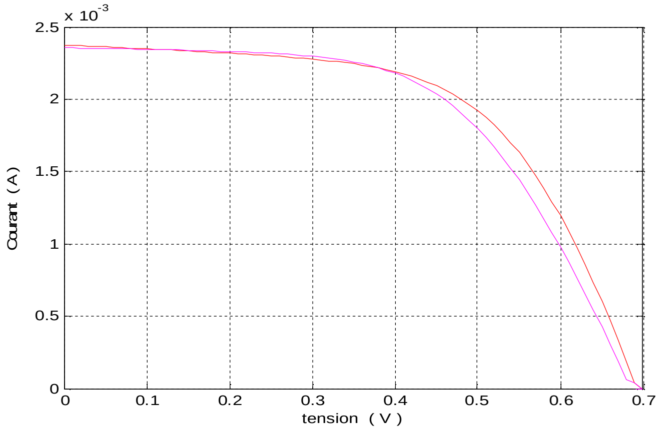

Figure 5. *I-V* characteristic of the group 2 compared to group 1.

Characteristic (*I-V*) shows us that the solar cell is a constant current source for low voltage values with a current approximately equal to current of short-circuit *I*cc. With the increase of the tension, the current begins to decrease exponentially to zero value where is equal to the tension of open-circuit V_{co} circuit. On the entire range of tension, there is one single point where the cell operates at the highest yield (the blue point "Fig. 4,"); which is the maximal point of power.

4.2.2. Influence of temperature on the *I-V* characteristic

To study the influence of the temperature we use the characteristic (*I-V*) of the group 1 and by simulating on Scilab we obtain the following figure:

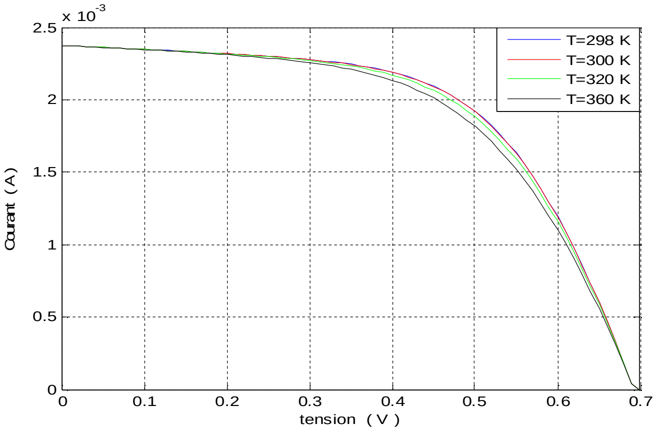

Figure 6. Influence of temperature on the *I-V* characteristic.

The temperature is an important parameter in the behaviour of cells. The increase of the temperature with a fixed illumination entails a net decrease of the tension of open-circuit (V_{co}) and an increase of the current short-circuit (I_{cc}), as well as a decrease of the maximal power (P_{max}). For a temperature, which changes from 25 to 87 °C, we can see that the variation of the tension changes much more than the current. The current of short-circuit, as for him, increases with an increase in the temperature.

4.2.3. Influence of the parallel resistance

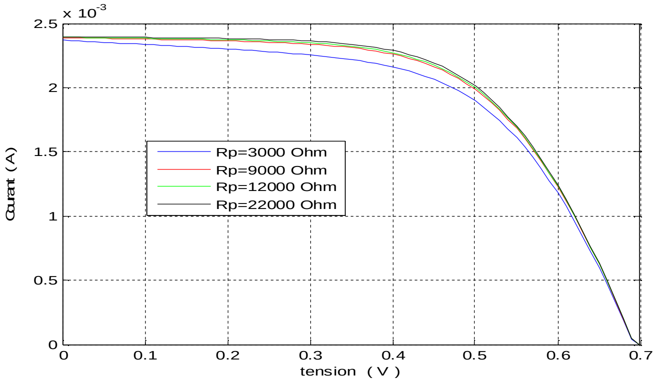

Figure 7. Influence of the parallel resistance on the *I-V* characteristic.

The influence of the parallel resistance (shunt) on the characteristic current-tension is translated by a light decrease of the tension of open circuit, and an increase of the slope of the curve *I-V* of the cell in the zone corresponding to a functioning as a source of current.

4.2.4. Influence of the series resistance

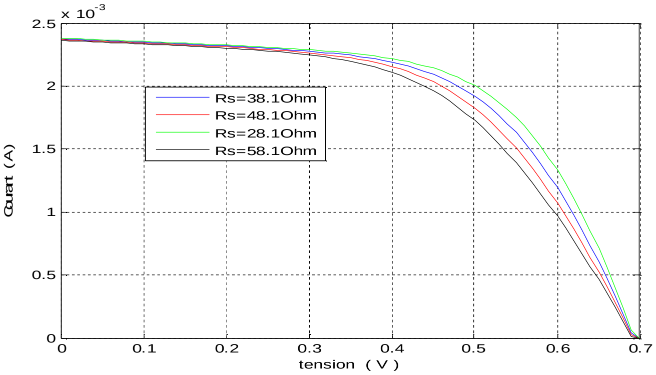

Figure 8. Influence of the series resistance on the characteristic *I-V*.

The series resistance acts on the slope of the characteristic in the zone where the photodiode behaves as a generator of tension, and when it is high, it decreases the value of current of short- circuit (I_{cc}), what is going to limit the yield of conversion.

5. CONCLUSION

The modelling of a solar cell is the performing tool, which will allow us by simulation, to link the photovoltaic characteristics of this cell with the internal properties of the material and the manufacturing technology to improve the performances of the cell.

In the present work, we have presented different models of electric characterizing photovoltaic cells, we became interested in a diode model for dye-sensitized solar cell.

The performances of a photovoltaic cell are degraded when, as R_s is big or as R_{sh} is low.
The information obtained from the equivalent circuit model of DSSC includes not only the cell network and system simulation, but also contributes to the analysis of electrical processes involved.

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