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Photovoltaic Cell Mathematical Modelling

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Abstract— **The photovoltaic cells description is usually defined by a coupled nonlinear equation, difficult to solve using analytical methods. This paper presents a mathematical model using Matlab/ simulink, able to demonstrate the cell's output features in terms of irradiance and temperature environment changes.**

***Keywords*— Photovoltaic cell, Matlab/Simulink, Model**

I. INTRODUCTION

In recent years, photovoltaic energy is increasingly used because of its important benefits. In fact, this type of energy ensures an electricity production without green house gases emission. Besides, photovoltaic energy is totally flexible and can meet a wide range of needs [1-2], [4], [8] and [11]. PV cell is the basic unit of power conversion system of a photovoltaic generator [3]. Solar cells convert sunlight directly into electricity. Solar cells are widely used in terrestrial and space applications. They are made of semiconducting materials similar to those used in computer chips. A photovoltaic cell converts the solar energy into the electrical energy by the photovoltaic effect. When sunlight is absorbed by these materials, the solar energy knocks electrons loose from their atoms, allowing the electrons to flow through the material to produce electricity [9]. This process of converting light (photons) to electricity (voltage) is called the photovoltaic (PV) effect. In this paper, we present three models for a photovoltaic cell [10]. These models are characterized by the use of a single diode.

II. PV CELL MODELS

A. Nomenclature

V: cell output voltage (V).
Voc: open circuit voltage (V).
I_{pv}: cell output current (A).
I_{ph}: solar cell photocurrent (current generated by the incident light and it is directly proportional to the sun irradiation) (A).
I_{sat}: reverse saturation or leakage current of the diode (A).
I_d: diode current (A).
T_s: solar cell absolute reference temperature at STC = 298 K.
T: solar cell absolute operating temperature (K).
A: diode ideality factor.
K: Boltzmann constant = $1.3806.10^{-23}$ J/K.
q: Electron charge = $1.60217733\ 10^{-19}$ C.
R_s: cell intrinsic series resistance.
R_{sh}: cell intrinsic shunt or parallel resistance.
g: total solar radiation absorbed at the plane of array (POA), W/m^2.
g_s: total solar reference radiation at STC, 1000 W/m^2 .

TABLE I
PV CELL PARAMETRS

Parameters	Value
Vocs	0.6
Iccs	3.45
R_{sh}	11592
R_s	0.018
Δvoc	-0.0022
G_s	1000
T_s	298
A	1.2
K	$1.3806.10^{-23}$
Δicc	0.00095
Q	$1.60217733.10^{-19}$

B. Three-parameter model

It is considered as an ideal equivalent circuit for a photovoltaic cell and it is the simplest model [5] and [10].

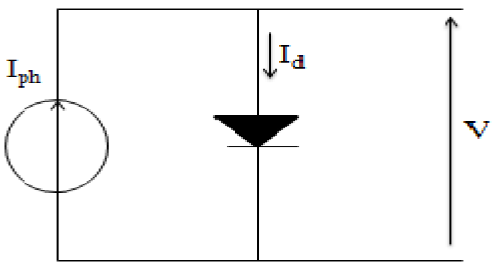

Fig. 1: three-parameter model

The three parameters are A_1, I_d and I_{ph}.

$$I_{PV} = I_{ph} - I_d \tag{1}$$

$$I_{ph} = iccs\frac{g}{g_s}(1 - \Delta icc(T_s - T)) \tag{2}$$

$$I_d = I_{sat}(e^{\frac{v}{\frac{TAk}{q}}} - 1) \tag{3}$$

$$I_{sat} = \frac{I_{ph}}{e^{\frac{V_{oc}}{\frac{TAk}{q}}} - 1} \tag{4}$$

$$V_{oc} = V_{ocs} - \Delta voc(T_s - T) \tag{5}$$

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C. Four-parameter model

This model takes into account resistors various contacts and connections represented by a series resistor R_s [1-3] and [5] and [10].

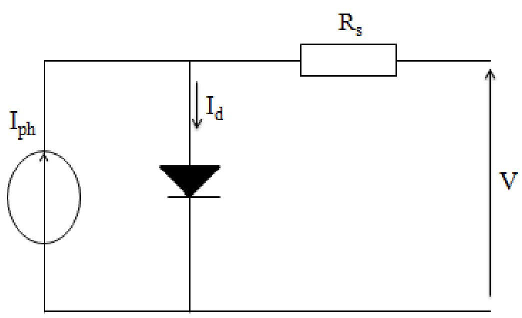

Fig. 2: four-parameter model

The four parameters are Rs, A, I_D and I_{ph}.

$$I_{PV} = I_{ph} - I_d \tag{6}$$

$$I_{ph} = iccs\frac{g}{g_s}(1-\Delta icc(T_s - T)) \tag{7}$$

$$I_d = I_{sat}(e^{q\frac{v+IR_s}{TAk}} - 1) \tag{8}$$

$$I_{sat} = \frac{I_{ph}}{e^{q\frac{V_{oc}}{TAk}} - 1} \tag{9}$$

$$V_{oc} = V_{ocs} - \Delta voc(T_s - T) \tag{10}$$

D. Five-parameter model

This model is the best known in the literature. It is composed of a current source which models the conversion of the light flux into electrical energy, a shunt resistor R_{sh} is the consequence of the state along the periphery of the surface of the cell, a series resistor R_s representing resistors various contacts and connections, and a diode which models the PN junction [4-5] and [10].

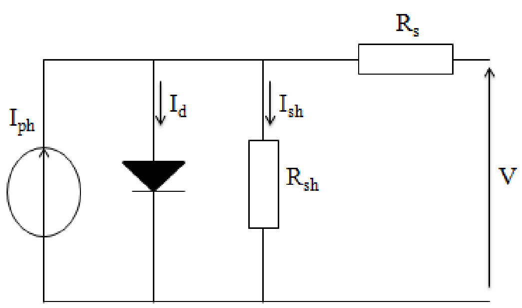

Fig. 3: five-parameter model (single-diode)

The five parameters are Rs, R_{sh} , A, I_d and I_{ph}.

$$I_{PV} = I_{ph} - I_d - I_{sh} \quad (1) \tag{11}$$

$$I_{ph} = iccs\frac{g}{g_s}(1-\Delta icc(T_s - T)) \tag{12}$$

$$I_{sat} = \frac{I_{ph} - \frac{V_{oc}}{R_{sh}}}{e^{q\frac{V_{oc}}{TAk}} - 1} \tag{13}$$

$$I_d = I_{sat}(e^{q\frac{v+IR_s}{TAk}} - 1) \tag{14}$$

$$V_{oc} = V_{ocs} - \Delta voc(T_s - T) \tag{15}$$

$$I_{sh} = \frac{v + I.R_s}{R_{sh}} \tag{16}$$

E. Simulation results

The simulation results obtained from these models are made under standard conditions (reference temperature: 25° (298 K) and reference illumination: 1000 W/m2). The comparison between the two models: the four-parameter model and the five-parameter model show that the effect of the shunt resistance R_{sh} is negligible. Besides, the series resistance R_s removing (four-parameter model and three-parameter model) creates a large difference between the test results and those presented by this model (Fig. 4 and Fig. 5). The five parameters model is the most simpler and accurate.

The different developed PV cell models characteristics are estimated as follows. I-V and P-V characteristics under two conditions: under varying irradiation with constant temperature (Fig. 6 and Fig. 7) and under varying temperature with constant irradiation (Fig. 8 and Fig. 9). The simulation results show that when the irradiation increases at a constant temperature, the output current increases and the output voltage also increases. This results in increase in power output with increase in irradiation at constant temperature. Similarly a temperature increase at a constant irradiation, the output current increases but the output voltage decreases. This results in reduction in power output with rise temperature.

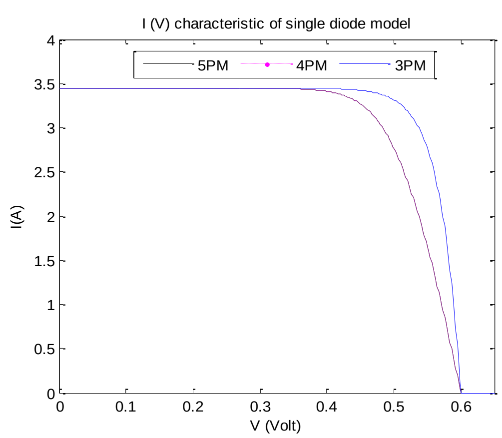

Fig. 4: I (V) characteristics (five-parameter model, four-parameter model and three-parameter model).

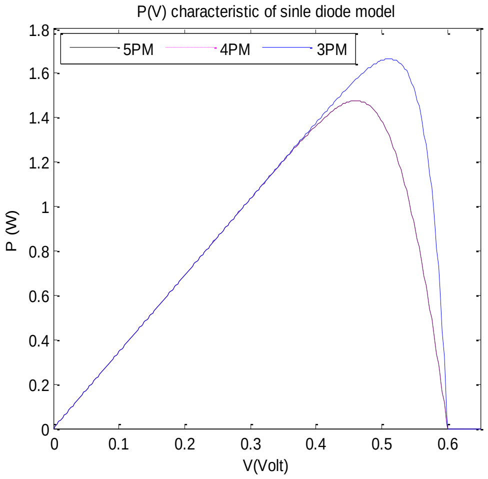

Fig. 5: P (V) characteristics (five-parameter model, four-parameter model and three-parameter model).

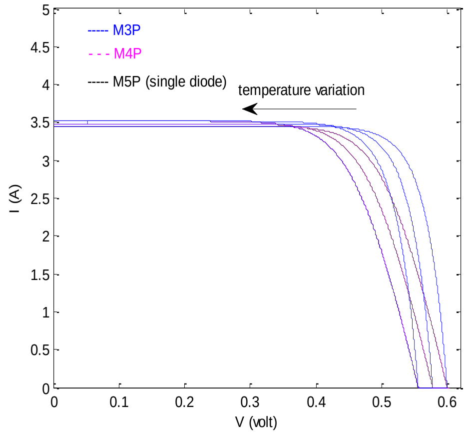

Fig. 8: The I (V) output characteristics of the different modelswith varying temperature.

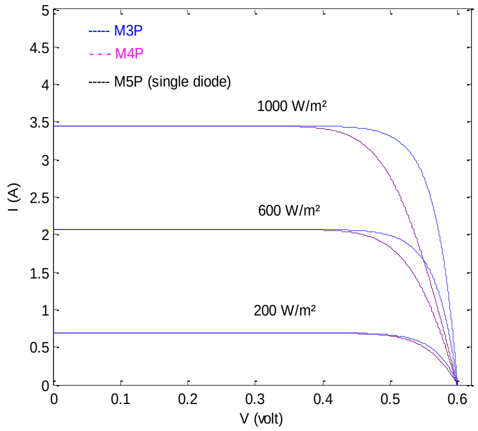

Fig. 6: The I (V) output characteristics of the different models with varying irradiation.

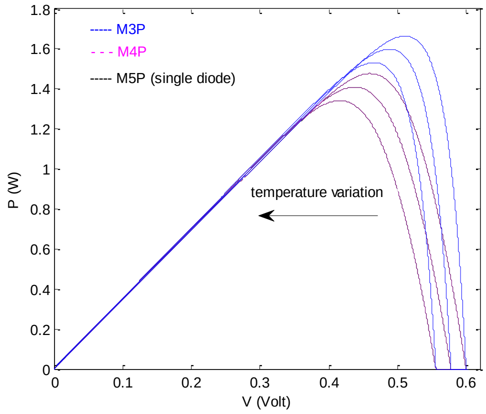

Fig. 9: P (V) output characteristics of the different models with varying temperature.

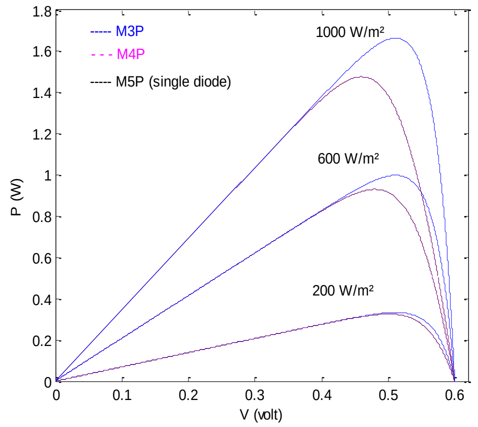

Fig. 7: The P (V) output characteristics of the different models with varying irradiation.

III. CONCLUSIONS

Photovoltaic modeling cells is important to describe their behavior under all conditions and ensure a closer understanding of I-V and P-V characteristics of a PV cell. The photovoltaic cells must be operated at their maximum power point. The maximum power point varies with illumination, temperature, radiation dose and other ageing effects.

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