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# Solar Module Modeling, Simulation And Validation Under Matlab / Simulink

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**ABSTRACT**
Solar modules are systems which convert sunlight into electricity using the physics of semiconductors. Mathematical modeling of these systems uses weather data such as irradiance and temperature as inputs. It provides the current, voltage or power as outputs, which allows plot the characteristic giving the intensity I as a function of voltage V for photovoltaic cells. In this work, we have developed a model for a diode of a Photovoltaic module under the Matlab / Simulink environment. From this model, we have plotted the characteristic curves I-V and P-V of solar cell for different values of temperature and sunlight. The validation has been done by comparing the experimental curve with power from a solar panel HORONYA 20W type with that obtained by the model.
***Keywords***: physics of semiconductors, Matlab / Simulink environment, solar modules

## I. INTRODUCTION

The use of renewable energies, particularly photovoltaic systems is growing more and more. These renewable energy sources are essential for the electrification of isolated areas that are not connected to distribution system. The photovoltaic system is the most used in the field of renewable energy **[1]**. It generates electricity in direct current, without major impact on the environment. However, to understand the operation of the photovoltaic system and estimate its production based on climatic conditions, it is necessary to represent it by a mathematical model based on a PV cell. The model can theoretically simulate the behavior of the photovoltaic system with respect to certain parameters such as sunlight, temperature and resistance. Researchers have developed different models of photovoltaic systems. Among them, the single diode model is the simplest model. It offers a good compromise between simplicity and accuracy. It is by the way the most widely used : **[2]**, with both series and parallel resistors to represent effect of irradiance and temperature on the PV module; **[3]**, to allow the interaction with a power converter **[4]** to find the best Current (I) voltage (V) equations for the single PV model and the effects of the series and parallel resistance; **[1]** to investigate I-V and P-V characteristics of a 36W solar module; **[5]**, to compare the data sheet values and characteristics of the PV module in Standard Test Conditions with experimental current (I) Voltage (V)characteristics of Solarex MSX60 module; **[6]** in a photovoltaic grid connected system modeling by a lumped circuit and parallel resistor and its experimental validation. Parameters model are needed in the single diode model. They can be estimated by direct calculation or measurement. Direct calculation is driven by mathematical model using software such as Matlab Simulink. **[7]** evaluate a simple analytical method for extracting parameters involved in the photovoltaic module behavior equation. **[4]** present a mathematical model of a Photovoltaic (PV) cell using Matlab-simulink environment to find the parameters of the nonlinear equation relating current (I) to voltage (V) equation by adjusting the curve at three points: open circuit, maximum power, and short circuit. **[8]** use a simple and successful method for evaluating the series resistance, the ideality factor, the saturation current and the shunt conductance in illuminated solar cells; their approach involves an auxiliary function and a computer- fitting routine. The calculation of the maximum power is very important in photovoltaic systems. It corresponds in fact to the condition of optimum use of the system. Many authors proposed PV power systems with Maximum Power Point Tracking (MPPT) control. **[9]** compare the performance of different MPPT methods that are currently used in a solar PV system and introduce a new MPPT technique which offers better performance. **[10]** perform a systematic analysis in modeling and evaluation the key subsystems to obtain the Maximum Power Point of a solar cell; their simulation uses one-diode equivalent circuit in order to investigate I-V and P-V characteristics. The

GUI model is designed with Simulink block libraries. **[11]** presents a new Matlab/Simulink model of a PV module and a maximum power point tracking (MPPT) system for high efficiency InGaP/InGaAs/Ge triple junction solar cell. In this paper, we present a one diode mathematical model with four parameters. This model characterizes a PV module by representing the current - voltage and voltage - power curves under different irradiance and temperature. Outputs of the model have been validated to that measured on the Honora PV module of 20 W.

## II. THEORY AND APPLICATION

Photovoltaic cell models have long been a source for the description of photovoltaic cell behaviors. The most common model used to predict energy production in photovoltaic cell modeling is the single diode circuit model **[11]**, shown in Fig. 1. This model includes a current source $I_{ph}$, which depends on solar radiation and cell temperature, a diode which the inverse saturation current $I_D$ depends mainly on the operating temperature, a series resistance $R_s$ characterizes the losses by the Joule effect of the inherent resistance of the semiconductor and losses through the collection grids and poor ohmic contacts of the cell. The high strength semi-conductor electrodes appreciably lower voltage and output current varies very slightly, which will limit the conversion efficiency and a shunt resistance $R_{sh}$, taking into account the resistive losses.

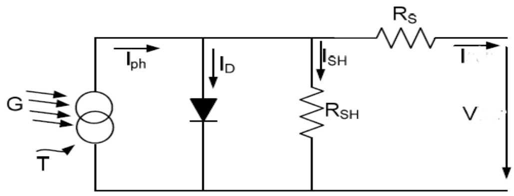



**Fig. 1.** Equivalent Electrical circuit of the single diode model.

The current–voltage relationship of a photovoltaic cell is given by Eq. 1:

$$I = I_{ph} - I_D - I_{SH} \qquad (1)$$

I represents the output current

$I_{ph}$ is the photocurrent, it is proportional to the incident flux. According to **[13]** its expression is (Eq 2)

$$I_{ph} = I_{sc}\frac{G}{G_{nom}} + k_0(T - T_1) \qquad (2)$$

Where

$$k_0 = \frac{I_{sc}(T) - I_{sc}(T_1)}{T - T_1} \qquad (3)$$

$I_{SC}$: Short Circuit Current

$K_0$: Current Proportionality constant. ($K_0$=2.2*$10^{-3}$ $^0$C).

G: Irradiance (W/m$^2$).

$G_{nom}$: Nominal Irradiance. ($G_{nom}$ =1000W/m$^2$).

$I_D$ (Eq 4) is the direct current of the diode. It has the same magnitude as $I_{SH}$ for low voltages it becomes very large around $V_{oc}$, the Open Circuit Voltage

$$I_D = I_0\left(\exp\frac{q(V + IR_s)}{nKT}\right) \qquad (4)$$

$I_0$ represents the reverse saturation current of the diode without irradiance. $I_0$ is calculated by the eq (5)

$$I_0 = \frac{I_{sc}(T_1)}{\exp\frac{qV_{co}}{nKT} - 1}\left(\frac{T}{T_1}\right)^{\frac{3}{n}}\exp\frac{-qE_g}{nK\left(\frac{1}{T} - \frac{1}{T_1}\right)} \qquad (5)$$

Where

T: is the cell operating temperature.

K: the Boltzmann universal constant (k = 1.38$e^{-23}$ J/K)

q: the electric charge (1.6 $10^{-19}$ C)

n: the ideality factor (1.2)

Isc: short Current

V: Operating Voltage (V)

$E_g$: Energy Band Gap ($E_g$ =1.12 eV)

$I_{SH}$ (Eq. 6) represents the current in the shunt resistance. It is the ratio of the voltage of the diode $V_D$ and series resistance$R_S$.

$$I_{SH} = \frac{V_D}{R_{SH}} = \frac{V + I * R_S}{R_{SH}} \qquad (6)$$

$I_{SH}$ is very low because the shunt resistor $R_{SH}$ is generally very large, so that it is independent of the voltage. It has been neglected for the rest of our study. The model used in our study is represented as follow (Fig.2).

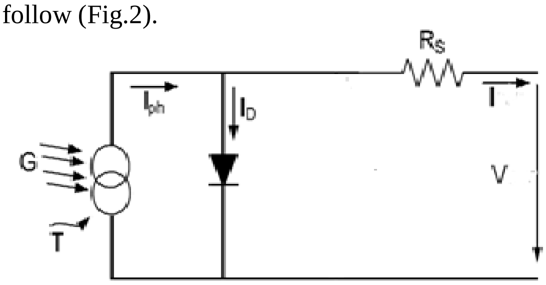



**Fig. 2**. Equivalent Electrical circuit of the single diode model.

Substituting equations 2 and 4 in Eq (1) we get:

$$I = I_{sc}\frac{G}{G_{nom}} + k_0(T - T_1) - I_0\left(\exp\frac{q(V + I*R_s)}{nKT}\right) \qquad (2) \quad (7)$$

According to Eq (7), the load current I depends on the temperature T, the voltage V, and the irradiance G.

**2-1 Determination Of Current Load I**

The current load of the cell is calculated by solving Eq (7) using the iterative Newton Raphson method. If I is a solution of equation (7), we set:

$$f(I) = I - I_{sc}\frac{G}{G_{nom}} + k_0(T - T_1) - I_0\left(\exp\frac{q(V+I*R_s)}{nKT}\right) \quad (8)$$

We have to solve

$$f(I) = 0$$

From a starting value, $I_i$ solution, we try

$$f(I_i) = 0$$

If the equation is true, $I_i$ is the right value. If not, we set

$$I_i = I_i + \Delta I_i$$

And replace in equation

$$f(I_i + \Delta I_i) = 0$$

We develop the first member in Taylor series at the first order

$$f(I_i + \Delta I_i) = f(I_i) + f'(I_i)\Delta I_i$$

$$f(I_i) + f'(I_i)\Delta I_i = 0$$

$$\Delta I_i = -\frac{f(I_i)}{f'(I_i)} \quad (15)$$

And the next value

$$I_{i+1} = I_i - \frac{f(I_i)}{f'(I_i)} \quad (16)$$

The iterative final equation is given as follow

$$I_{i+1} = I_i - \frac{I_i - I_{sc}\frac{G_i}{G_{nom}} + k_0(T_i - T_1) + I_0\left(\exp\frac{q(V_i+I_iR_s)}{nKT_i}\right)}{1 + \frac{I_0}{nKT_i}I_0\left(\exp\frac{q(V_i+I_iR_s)}{nKT_i}\right)}$$

(17)

In this equation, i is the time index (hour). $G_i, T_i$, $V_i$ are measured values, $R_s$ is a unknown constant with low value to be calculated using the STC (Standard tests Conditions)

**2-2 Determination Of Rs.**

The electro-physical output rating of P-V modules are given at specific conditions. These Conditions are called Standard Test Conditions (STC) they are given in the table 1.

**Table 1:** Standard test condition

| Parameter | Symbol | Value | Unit |
|---|---|---|---|
| Irradiance at normal incidence | G | 1000 | $Wm^2$ |
| Cell temperature | T | 25 | $^oC$ |
| Solar spectrum | AM | 1. 5 | - |

G, T are fixed to the values indicated the table 1 corresponding to the STC (Standard tests Conditions). For different values of $R_s$, equation (17) is solved against $V_i$. The resulting I-V curves are adjusted to the constructor experimental curve at three points: open circuit, maximum, and short circuit **[4]**. Final $R_s$ is the value corresponding to the best fit.

(9)

**2-3 Calculation Of Output Power**

The electric power corresponding to each step i is estimated by Eq (18). (10)

$$P_i = I_i\ V_i \quad (18)$$

The P-V characteristic is obtained by plotting P against V.

The maximum power $P_{max}$ is the top of the curve P-V (11)

(12)

## III. SIMULATIONS OF I-V CURVES P-V CURVES AND VALIDATION

The PV- module of the type HORONYA (13) has been chosen for the simulation. It delivers a power of 20W is chosen. Its characteristics are given (14) in table 2.

**Table 2:** Characteristics of the PV Module

| Specifications | Value |
|---|---|
| Open circuit voltage ($V_{oc}$) | 21 V |
| Short circuit current ($I_{sc}$) | 1.39 A |
| Maximum power voltage ($V_{mpp}$) | 17.28 V |
| Maximum power current ($I_{mpp}$) | 1.16 A |
| Maximum power rating ($P_{max}$) | 20 W |
| Temperature coefficient _ $I_{sc}$ | 0.064 |

Equation (17) is solved iteratively by using MATLAB. Voltage (Vi) measured from the PV module at different time step i, irradiance values (Gi), and temperature (Ti) are inputs. I-V and P-V characteristic curves are then plotted

## IV. RESULTS AND DISCUSSIONS

In figure 3, we present an example of I-V characteristic (Fig 3(a)) and P-V characteristic (Fig 3(b)). I-V characteristic presents three zones AB, BC and CD.

AB: the current load is almost constant; the resistance load is low. The photovoltaic module behaves as a current source.

BC: the module delivers the highest power and its efficiency is maximum. It is neither a current source, nor a voltage source.*

CD: the voltage is almost constant. The photovoltaic module behaves like a voltage source.

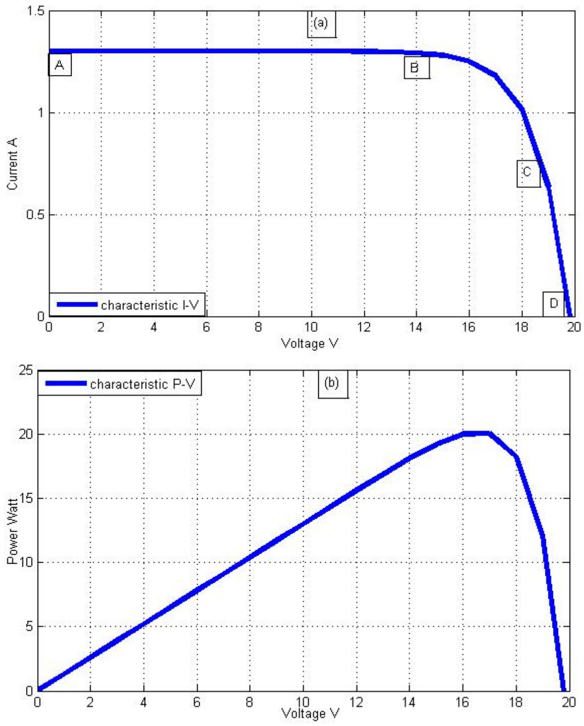



**Figure 3:** characteristic of the module (a) I V, (b) P-V

**4-1 Influence Of Sunshine**

Temperatures are chosen from the STC conditions. For each of the decreasing irradiance values (1000, 900, 700, 500 W/m²) load current I and power P are calculated for different values of V. Characteristics curves I-V, and P-V are then plotted (Fig 4) : when the irradiance decreases, the short current $I_{sc}$ and the court circuit voltage $V_{oc}$ decreases also, and by the way the power P.

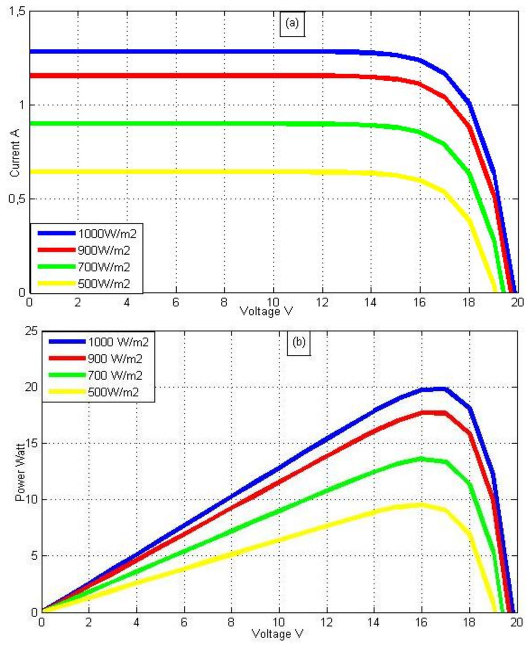



**Figure 4:** The influence of Irradiance on the characteristic (a) I-V, (b) P-V

**4-2 Influence Of Temperature**

Irradiance is fixed to G = 1000W / m². Four Values of temperatures are selected: 0°C, 25°C, 50°C, and 75°C. The characteristic curves I-V and P-V are plotted for each of, these temperatures (Fig 5). When the temperature increases, voltage V (Fig 5a) and the power P (Fig 5b) decrease.

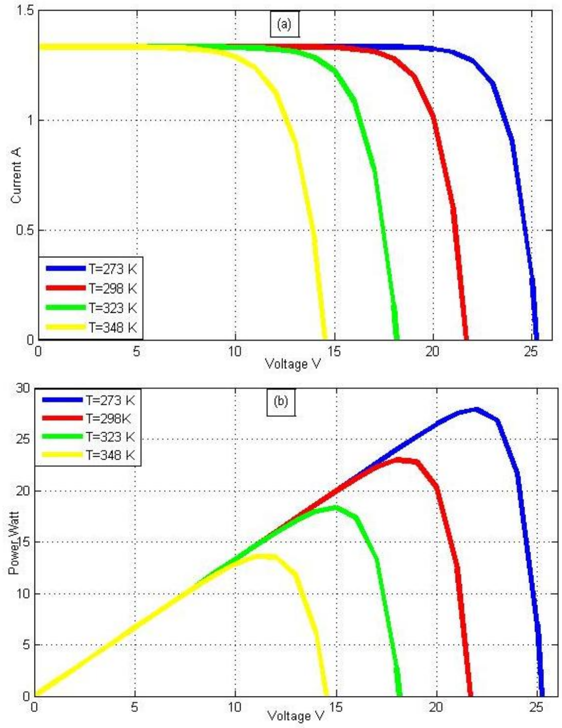
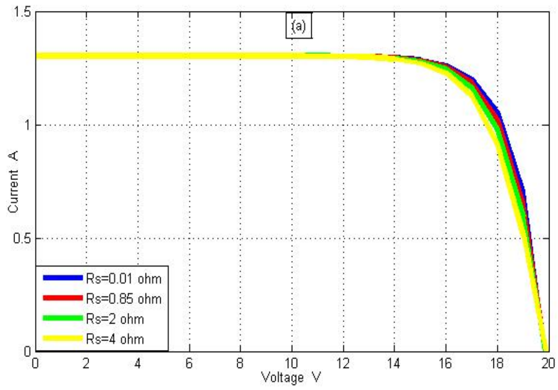



**Figure 5:** The influence of temperature on the characteristic (a) I-V,(b) P-V

**4-3 Influence Of The Series Resistance**

For three of $R_s$ (0.01Ω, 0. 85Ω, 2 Ω, and 4 Ω) the I-V and P-V characteristics curves are plotted (Fig 6). Fig 6.a shows that $R_s$ does not affect the short circuit current Isc and the open circuit voltage Voc. As $R_s$ increases, the slope of the characteristic curve decreases. Furthermore, according to Fig 6.b the maximum power decreases when the resistance $R_s$ increases.



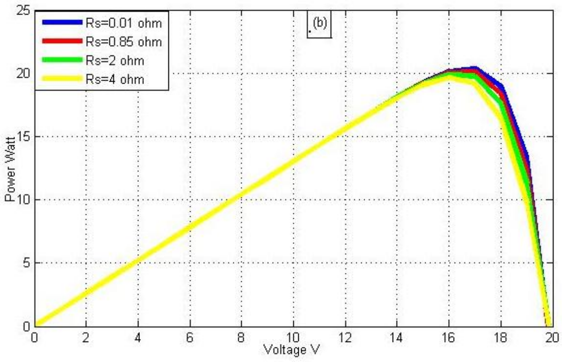



**Figure 6:** the influence of series resistance on the characteristic (a) I-V, (b) P-V

### 4-4 Validation

To validate our model, we compare the powers calculated by the model to that measured on the HORONYA 20W-type solar module for three days (Fig 7). We have noted an under estimation of the powers calculated by the model, particularly during the day in bright sunlight. This occurs because high values of Isc and $V_{co}$ are used in measured powers.

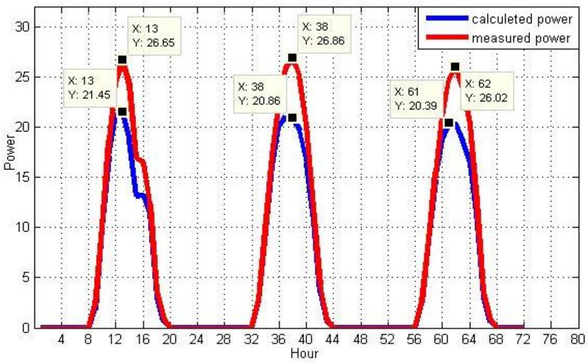



**Figure 7:** Comparison of the theoretical model and the experimental data.

## V. CONCLUSION

We presents in this paper a one diode model equivalent with four parameters. Equation for load current is solved iteratively using Newton Raphson under Matlab Simulink environment. Inputs for the model are voltage, temperature, and sunlight; output is is the current supplied by the module. The parameters of the HORONYA photovoltaic module are used in the simulation. We have noted the following results: as the temperature or the Rs resistance increases, the power decreases; as the irradiance increases, the power increases. We have then compared the power calculated by the model to that measured on a 20W HORONYA PV module. During the high sunlight, the model underestimates the power. This comes from the high values of $I_{SH}$ and $V_{oc}$ used in the measured powers. Further research can be made by taking into account the $R_{SH}$ .Previous research will be conducted in the HORONYA module by introducing in the model other environmental parameters such as the relative humidity, dust, ...

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