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Matlab-Simulink of photovoltaic system based on a two-diode model simulator with shaded solar cells

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Abstract - *This paper proposes a photovoltaic system modeling and characterization software based on Matlab-Simulink in order to estimate the parameters and the characteristic and electrical behavior of a cell/module with respect to changes in environmental parameter regarding irradiance, temperature, and surface conditions (partial shading). The first objective is to find the parameters of the nonlinear I–V equation by adjusting the curve regarding three particular points: open circuit, maximum power, and short circuit. Given these three points, which are provided by all commercial module datasheets, the method finds the best I–V equation for the two-diode photovoltaic (PV) model, with the best series and parallel resistances estimates. The accurateness of the simulator is verified by applying the model to different manufacturer's modules. Thanks to an interactive graphic interface, this software offers a great flexibility to PV professional and to researchers.*

Résumé - *Cet article propose une modélisation du système photovoltaïque et des outils d'aide à la caractérisation basée sur Matlab - Simulink afin d'estimer les paramètres et le comportement caractéristique et électrique d'une cellule / module en tenant compte de l'évolution des paramètres environnementaux relatifs à l'éclairement, la température et les conditions de surface (ombrage partiel). Le premier objectif est de trouver les paramètres de l'équation I-V non linéaire, en réglant la courbe sur trois points particuliers: circuit ouvert, puissance maximale, et de court-circuit. Compte tenu de ces trois points, qui sont fournis pour tous les modules sur un fichier, la méthode pour trouver la meilleure équation I-V pour le modèle photovoltaïque de deux diodes (PV), avec la meilleure série et les estimations des résistances parallèles. L'exactitude du simulateur est vérifiée par l'application du modèle à des modules de différents fabricants. Grâce à une interface graphique interactive, ce logiciel offre une grande flexibilité pour le professionnel PV et aux chercheurs.*

Keywords: Photovoltaic (PV) solar cell - Bypass diode - Blocking diode - Partial shading - Maximum power point tracking (MPPT) - Matlab/Simulink – Simulator.

1. INTRODUCTION

Due to its inexhaustible and environmentally friendly energy, the research in solar energy has become an increasingly important topic in recent years. It is envisaged to become one of the most important renewable energy sources. It is one of the most

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promising alternatives for conventional energy sources. Due to this, photovoltaic solar energy has been increasingly used to generate electric power [1, 2, 11].

The aim, of this paper, is to provide the reader with all necessary information to develop photovoltaic models that can be used in simulation of photovoltaic systems. To improve accuracy, the two-diode model has been used. On the other hand, the iterative numerical Newton-Raphson method has been applied for the (R_p, R_s) computation model parameters.

To solve the problem of a PV source containing a number of cells connected in series and parallel under partially shaded conditions becomes a big challenge to find the best maximum power point (MPP) since its characteristics have more non-linearity with multiple local maxima [2]. This paper proposes a practical model and simulation method, which can predict the $I-V$ and $P-V$ module characteristics curves. It can be used to study the effect of temperature and irradiation variations, under shading variation. The simulation is developed using the Matlab-Simulink environment.

2. PHOTOVOLTAIC MODEL

To find the photovoltaic generator model, we must first find the electrical equivalent to that source. Many mathematical models have been developed to represent their highly nonlinear behavior resulting from semiconductor junctions. It describes PV modules accurately with temperature and solar irradiance dependency [4].

2.1 PV cell modeling

Many equivalent circuits have been proposed in the literature in order to assess the behavior of the PV cell. In our case, we consider the two-diode model which provides an even better description of the solar cell [15].

The two-diode model is depicted in Fig. 1. Using Kirchhoff's first law, the output current of the cell is given by [6, 7]:

$$I = I_{PV} - I_{d1} - I_{d2} - \frac{V + I \times R_s}{R_p} \tag{1}$$

where,

$$I_{d,\, i=\{1,2\}} = I_{0i} \exp\left(\frac{V + I \times R_s}{a_i \times V_T}\right) \tag{2}$$

with, $V_T = (k \times T)/q$ is the thermal voltage; q, the electron charge (1.602 10^{-19} C); k, the Boltzmann constant (1.38 10^{-23} J/k); T, the temperature of the p-n junction.

2.2 PV module modeling

A photovoltaic module is the basic element of each photovoltaic system. It consists of many jointly connected PV cells. The equivalent module circuit equation for an (N_{cell}) PV cells in series, leads to equation (3) [6, 7].

$$I = I_{PV} - I_{d1} - I_{d2} - \frac{V + I \times R_s \times N_{cell}}{R_p \times N_{cell}} \tag{3}$$

$$I_{d,\, i=\{1,2\}} = I_{0i}\left(\exp\left(\frac{V + I \times R_s \times N_{cell}}{a_i \times V_T \times N_{cell}} \right) - 1 \right) \tag{4}$$

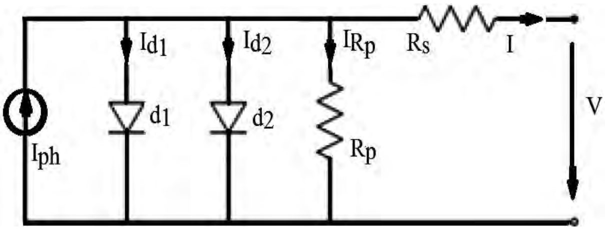

Fig. 1: Equivalent two diode circuit model of PV cell

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2.3 Improving, adjusting the model

All PV module datasheets bring basic information with reference to the standard test conditions (STC's). Some of the parameters, required for adjusting PV system models, such as R_s and R_p, are not specified. So, to use a more accurate model, these parameters are calculated simultaneously, using the datasheet information which is: open circuit, maximum power, and short circuit. This is done thru Newton-Raphson algorithm in order to compute, from equation (3), the module output current [8].

Newton-Raphson algorithm has the advantage of a very quick convergence for initial values near the root, as given in equation (5). So, within a few iteration steps, a good solution, of R_p in function of R_s, equation (6), is computed until the maximum experimental power value coincides with the (V_{mp}, I_{mp}) maximum power point, $P_{max,m} = P_{max,e}$, found in the corresponding module datasheet [7].

$$R_{p0} = \left(\frac{V_{mp}}{I_{sc} - I_{mp}} \right) - \left(\frac{V_{oc} - V_{mp}}{I_{mp}} \right) \tag{5}$$

where V_{mp}, Voltage at maximum power; I_{mp}, Current at maximum power; I_{sc}, Short circuit current, V_{co}, Open circuit voltage These four parameter values are found in the commercial datasheet.

$$R_p = \frac{V_{mp} + I_{mp} \times R_s}{I_{PV} - I_0\left[\exp\left(\frac{V_{mp} + I_{mp} \times R_s}{V_T}\right) + \exp\left(\frac{V_{mp} + I_{mp} \times R_s}{(p-1) \times V_T}\right) - 2\right] - \frac{P_{max,e}}{V_{mp}}} \quad (6)$$

2.4 PV cell/module under partial shading

The power generated by PV panels depends on irradiance, temperature and shading conditions. It is difficult to maintain uniform irradiance on all the cells at all times so the performance of the module is affected. Such a problem may arise due to the clouds, neighboring buildings, dirt, … [11].

Under one of those partial shading conditions, the power from the PV module can be dramatically reduced. Cells/modules under shade absorb a large amount of electrical power, generated by the other cells/modules under high irradiation, and convert it into heat.

This heat may damage the low illuminated cells/modules under certain conditions. To relieve the stress on shaded cells/modules, bypass diodes and blocking diodes are added across and between the modules respectively. In such a case multiple peaks in power-voltage characteristics are observed under non uniform illumination [8, 10].

3. SIMULATION AND RESULTS OF PROPOSED SOFTWARE

This section describes the procedure and results using the present interactive graphic interface menu with four main parts (Fig. 2). Furthermore, all inputs simulator parameters are available from the manufacture's datasheet.

The simulator computes R_s, R_p PV parameters and shows trough the curve plotting, the effects of temperature, irradiation, shading, and diodes (bypass and blocking).

In order to avoid damaging the cells, because of the hot spots, manufacturers have connected bypass diodes in parallel with PV cells. Typically, one bypass diode is connected with a string (1 string corresponds to18 cells in series) [12].

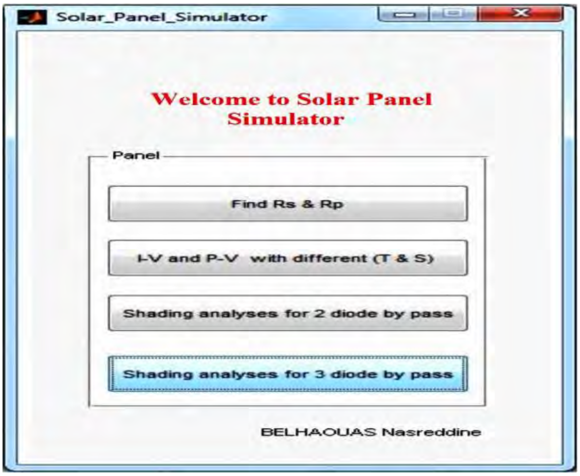

Fig. 2: PV simulator window menu

3.1 Find R_s and R_p

The experiment is done on one Siemens module, the SM55 [19]. The two diodes model and its parameters extractions such as (R_s , R_p) and $I-V$ and $P-V$ curves at standard test conditions are described in this interactive graphic interface, (Fig. 3).

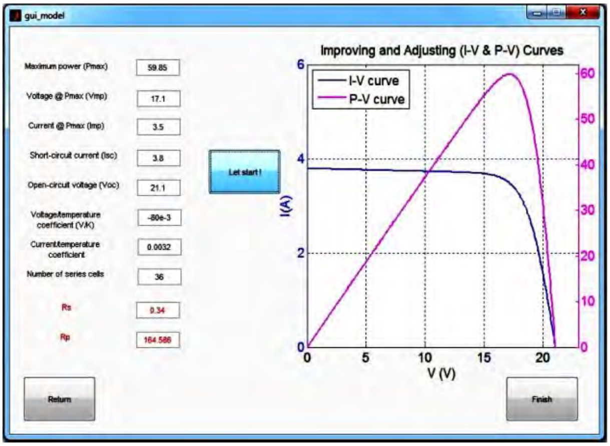

Fig. 3: Computed (R_s , R_p) and ($I-V$, $P-V$)
characteristics curves at STC for SM55 PV module

3.2 $I-V$ and $P-V$ characteristics for various temperature and irradiation values

Figure 4 shows how the simulator takes into account the variation of temperature and irradiation by drawing the different curves. The curves below corresponds to 50°C and 750 W/m^2.

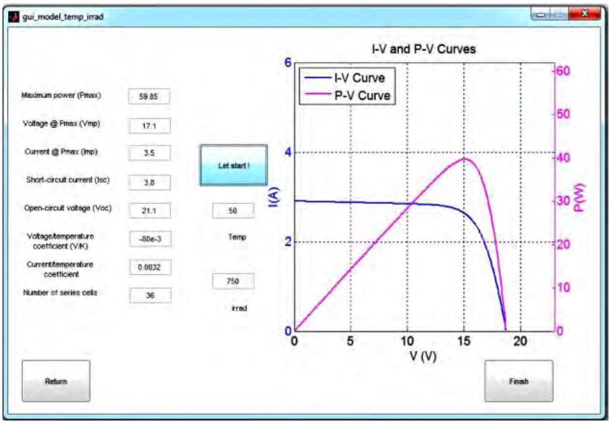

Fig. 4: ($I-V$, $P-V$) simulator block window characteristics curves for various temperature and irradiation for SM55 PV module (Temp = 50°C, Irrad = 750 W/m^2)

3.3 Shading analyses for two diode by pass

Fig. 5 shows the different input parameters window of the simulator. The effect of partial shading, for a two diodes, is shown in Fig. 6 thru the two peak power points.

Their values are clearly far from each other in this case. It indicates that a number of peak may appear when the same number of strings are connected in parallel with diodes. The number of peaks cannot be greater than the number of strings connected in parallel with bypass diode.

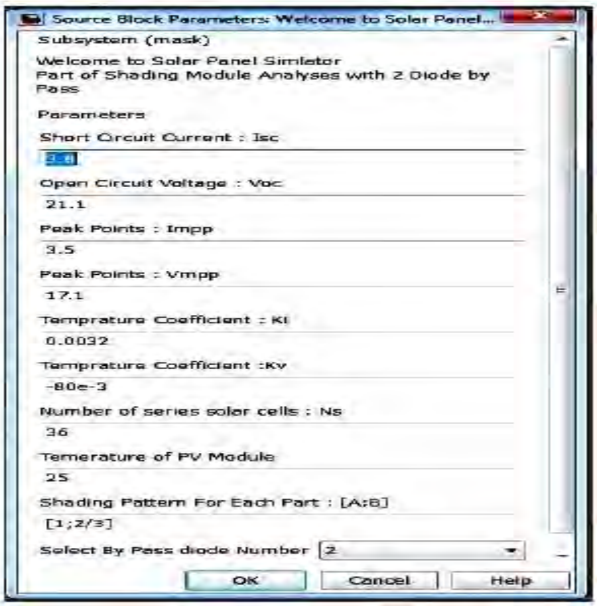

Fig. 5: PV block input parameters window
for SM55 PV module with two bypass diode

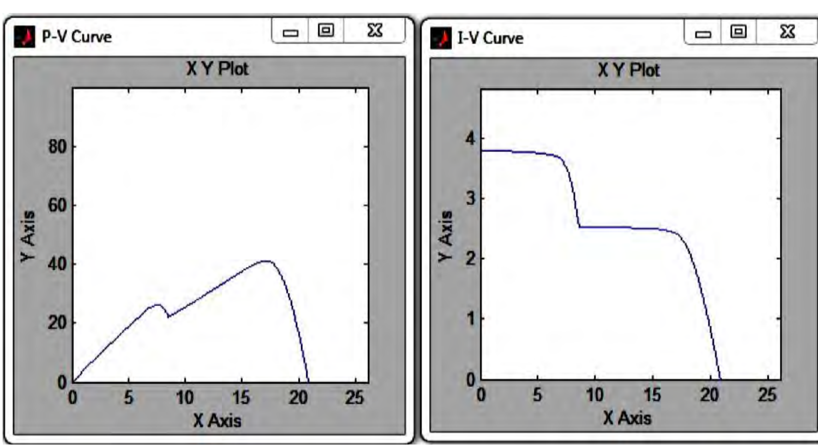

Fig. 6: (I−V , P−V) characteristics curves at various temperature and irradiation for each string (Temp = 25°C, Irrad = 1 kW/m^2, 2/3 kW/m^2) from simulator for SM55 PV module with two bypass diode

3.4 Shading analyses for three diode by pass

As shown from the previous simulation the principle stays the same for three bypass diodes. This time, a different manufacturer module, the MSX-60 [20], is used in this experimental simulation, (Fig. 7). It shows three peaks power values far from each other under partial shading conditions, (Fig. 8).

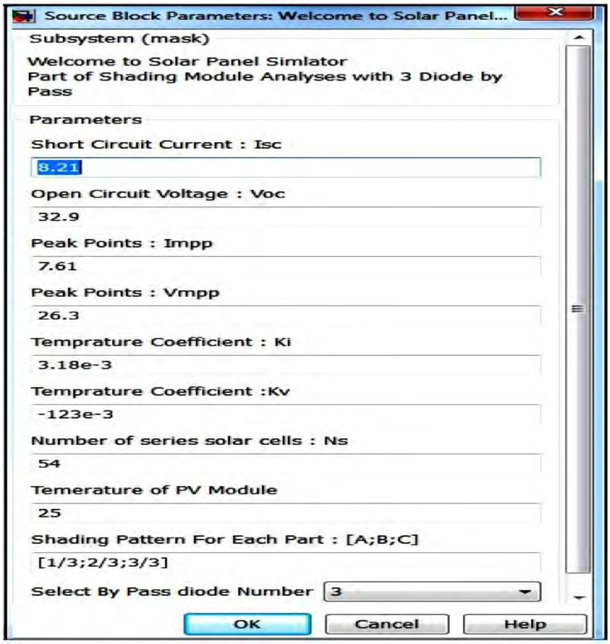

Fig. 7: PV block parameters window for MSX-60 PV module with three bypass diode

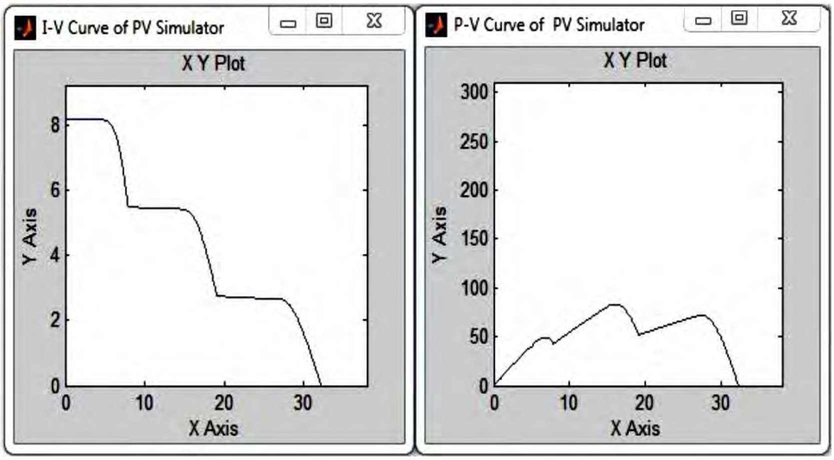

Fig. 8: (I − V , P − V) characteristics curves at various temperature and irradiation for each string (Temp = 25°C, Irrad = 1 kW/m^2, 2/3 kW/m^2) from simulator for SM55 PV module with two bypass diode

4. CONCLUSION

The paper presents a Matlab/Simulink simulator model of PV cells/modules under partial shaded conditions. The simulator finds the equivalent circuit parameters of different kind of two diodes PV modules model. The (R_s, R_p) were estimated by Newton–Raphson numerical technique. It allows us to observe the ($I-V$ and $P-V$) characteristics curves of any PV manufacturer modules. It can be used to predetermine the behavior of different PV modules having different number of strings-bypass diodes connections under shadow conditions. We can conclude that the energy production increases when the strings-bypass diodes connections is higher. This is shown in the last tests. But multiple peaks MPP cause the need of a more complicated MPPT.

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