Solar Photovoltaic Modeling and Simulation Using Matlab / Simulink and the Effects of Partial Shading on PV Array

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Solar photovoltaic modeling and simulation using Matlab / Simulink *and the Effects of Partial Shading on PV array*

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Abstract. In renewable power generation, solar photovoltaic as clean and green energy technology plays a vital role to fulfill the power shortage of any country. Modeling, simulation and analysis of solar photovoltaic (PV) generator is a vital phase prior to mount PV system at any location, which helps to understand the behavior and characteristics in real climatic conditions of that location. Modeling, through the characterization of the cell model, panel and system (fields) of photovoltaic panels we show the simulation results by the influence of parameters that come into play in the performance of solar electric power generation such as solar radiation, temperature, serial resistor Rs, the shunt resistor Rsh. The chosen model in this paper is the single diode model with both series and parallel resistors for greater accuracy.This work also is interested about the effect of shade on photovoltaic array and his impact on different characteristic of Gpv. The detailed modeling is then simulated using Matlab /Simulink.

Keywords : photovoltaic, modeling, simulation, radiation, temperature, Matlab/Simulink, shading

Introduction

Currently the energy consumption is in increase due to the trend of Rapid industrialization and evolution demographic, which leads to the consumption of Stock of energy sources come from fossil fuels, wich rise in the global warming effects and climate change issues. so, it is expected that the global ambient temperature will increase by approximately 2 °C by 2050 due to the pollutant emissions[1].

Search for renewable energy sources and their technology developement is of paramount importance to have a balance and buoyant environment for better quality of life. Energy supply from renewable sources is therfore an essential part of every country's straegy.[2]

Solar energy is the most encouraging source of energy and the most powerful among renewable energies due to it's non polluting and inexaustible nature[3] . Electricity photovoltaic is the result of a direct transformation of the light of the sun in electricity by means of PV cells. They are essentially consisting of a PN junction[4]. Photovoltaic modules or solar panels are the most fundamental components in a photovoltaic power system which is used to convert solar energy to electrical power[5] [6] [7]. So, the PV designers are in need of a reliable and flexible tool to predict the power generation by the PV systems of various sizes. The solar PV modeling is being updated endlessly to help the researchers for a better understanding of the operation. Depends on the various simulation software's such as Matlab, Simulink, C-program, Sci-lab, LTSpice, etc.[8]

Shading is the not unusual occurrence that dealing with the PV array via the transiting clouds, shade of tuft, progress buildings, filth, particles, fowl dung, various trends and slopes, and so forth. The partial shading on PV array rises decrease in product power. In a PV module the shading effects not just power decrease however as well leads into hot-spot and purposes harm to these cells, a bypass diode is jointed in parallel with a PV module [9]. Shadow effect relies on module kind, bypass diode position, string order and strength of shadow. Power damage show of shadow, as well current mismatch inside a PV string and voltage mismatch among parallel strings[10]

In the present paper, modeling of a photovoltaic is developed using Simelectronics (Matlab/Simulink) environment . through the characterization of the cell model, panel and Array PV we show the simulation results by the influence of parameters that come into play in the performance of solar electric power generation such as solar radiation, temperature, serial resistor Rs, the shunt resistor Rsh[11] , and illustrate the outcomes of partial shading with bypass diode and without bypass diode on the I(V) and P(V) traits of the photovoltaic panel .

1. Presentation and modeling of the solar cell

1.1. Working principle of solar cell

A photovoltaic cell is composed of a semiconductor material that absorbs light energy and transforms it directly into electric current.The sunlight is composed of photons whose energy is inversely proportional to the wavelength. The radiation arriving on the solar cell will be for a part reflected, for another part absorbed, the rest will pass through the thickness of the cell.Only the absorbed photons generate electricity [12]

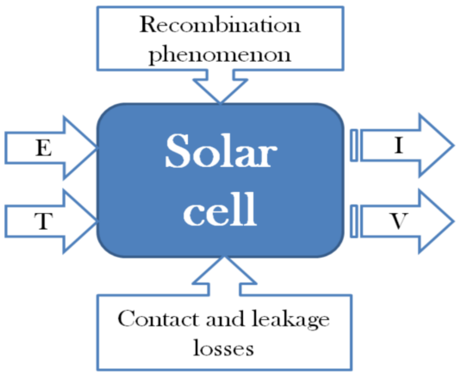


Figure 1: General presentation of a Solar cell

1.2. Mathematical model of real PV (cell/model/array)

I.2.1. Mathematical model of real PV cell

In this paper a more realistic circuit model of solar PV cell is devoloped. It is presented as real single diode model with series resistance (Rs),wich considered as losses by Joule effect, it is primarily due to metal grids, semiconductor materials, collecting bus, and its connections. and parallel resistance (Rp) , it is associated with seepage of current due to the cell thickness, surface effects and called as shunt resistance.the appropriat model is illustrated in figure 2.

In the ideal case Rs and Rp are ignored but in reality it is not possible to overlook these resistances, because efficiency of the PV solar cell is affected by these parameters.

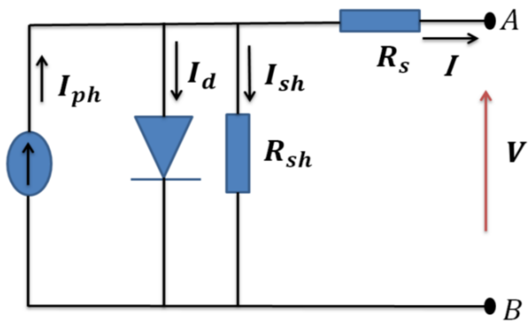


Figure 2: Equivalent circuit of real model for PV panel

In figure 2 and by Applying Kirchhoff's law, the current will be obtained by the following equation :

$$I = I_{ph} - I_d - I_{sh} \qquad (1)$$

I_d is The current of the diode which is proportional to the saturation current, and From the theory of semiconductors the fundamental mathematical equation that describes the I–V characteristics of the PV solar cell known as Shockley's diode current equation as illustrated in Equation (2) [12] :

$$I_d = I_0 \left[exp\left(\frac{q(V+IR_s}{KAT_r}\right) - 1\right] \qquad (2)$$

$I_{sh}$is the current that flows in the parallel resistance, is given by the following equation :

$$I_{sh} = \frac{\mathrm{V+I}R_s}{R_{sh}} \qquad (3)$$

I_0 is the saturation current (A), q = 1.602 × 10−19 (C) charge of an electron, K=1.380 × 10−23 (J/K) Boltzmann's constant, T_r real-time temperature (K), R_s series resistance of the PV module (Ω) ,R_{sh} Parallel resistance of the PV module (Ω) and A the ideal factor that depends on PV technology.

By putting value of the I_d and I_{sh} in Equation(1) the characteristic voltage-current equation of a solar cell is given as follow :

$$I = I_{ph} - I_0 \left[exp\left(\frac{q(V+IR_s}{KAT}\right) - 1\right] - \frac{V+IR_s}{R_{sh}} \qquad (4)$$

The current photo depends mainly on the sunshine and the operating temperature of the cell, which is described by the following equation :

$$I_{ph} = \left[I_{sc} + K_i \,.\, (T_0 - T_{ref})\right] - \frac{G}{G_{ref}} \qquad (5)$$

I_{sc} short-circuit current at STC (A), K_i =0.005254 (A/◦C) temperature coefficient of Isc cell short circuit current, T_{ref} = 25 + 273 = 298 (K) cell temperature at STC condition , G solar irradiance (W/m²) and G_{ref}= 1000 [W/m²] solar Irradiance at STC conditions.On the other hand, the saturation current of the cell varies with the temperature of the cell, which is described as follows :

$$I_0 = I_{rs} \left(\frac{T_0}{T_{ref}}\right)^3 . \, exp\left(\frac{q.Eg(\frac{1}{T_{ref}} - \frac{1}{T_0}}{KA}\right) \qquad (6)$$

I_{rs} is the reverse saturation current of the cell at a reference temperature and a solar radiation Trtc (A), Eg = 1.1 eV forbidden Energy band gap, for silicon.
The inverse saturation current is given by the following equation :

$$\mathrm{I_{rs}} = \frac{\mathrm{I_{sc}}}{\mathrm{exp}\left(\frac{\mathrm{q.V_{oc}}}{\mathrm{N_S.A.KT_0}}\right) - 1} \qquad (7$$

1.2.2. Mathematical model of PV module

A typical PV cell produces less than 2W at about 0.5V ,The association of several PV cells in series/parallel results in a photovoltaic panel . If the cells are connected in series, the voltages of each cell add up, increasing the total voltage of the generator. On the other hand, if the cells are connected in parallel, it is the the amperage that will increase.The equivalent circuit for a solar module with Ns number of cells connected in series and Np number of cells connected in parallel is shown in Figure 3.

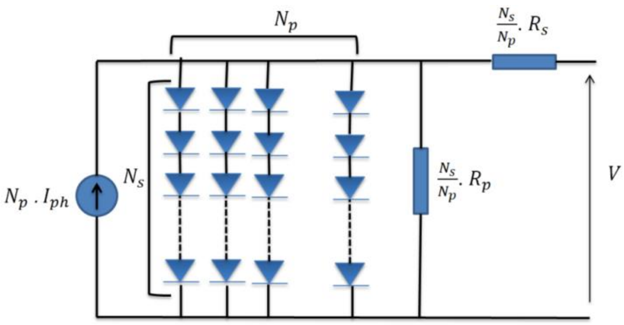


Figure 3: General model of a photovoltaic panel

The terminal equation for the current and voltage of a PV module becomes the following equation:

$$I = N_p.I_{ph} - N_p.I_0\left[\exp\left(\frac{q(\frac{V}{N_s}+\frac{IR_s}{N_p})}{KAT}\right)-1\right] - \frac{(\frac{N_p.V}{N_s}+IR_s}{R_{sh}} \qquad (8)$$

To develop the modeling and carry out the simulation of a solar panel model, MSX-60W PV panel Specifications. The module is consists of 36 polycrystalline silicon solar cells connected in series. The effectiveness of the PV model is to predict the Voc, Isc and the Pout accurately for STC conditions. The physical parameter such as Voc, Isc, Vmpp, Impp, and Pmax at 25 °C constant temperature is compared with the parameters predicted by the PV model, and the comparison is presented in Table 2.

Table 2. MSX-60W PV Module Specifications.

Parameter specification	Values
P_{mpp}	60 W
V_{mpp}	17.1 V
I_{mpp}	3.5 A
I_{SC}	3.8 A
V_{OC}	21.1 V
N_s	36
A	1.3

2. **Simulation**

2.1. PV photocurrent model

This block represents the photocell current and act as a subsystem in solar cell model according to equation 5 as shown in figure 4. The photocurrent behaves linearly on the solar irradiance (w/m²) and also affected by short circuit current (A), reference temperature (Kelvin) and operating temperature (Kelvin). [13] [12]

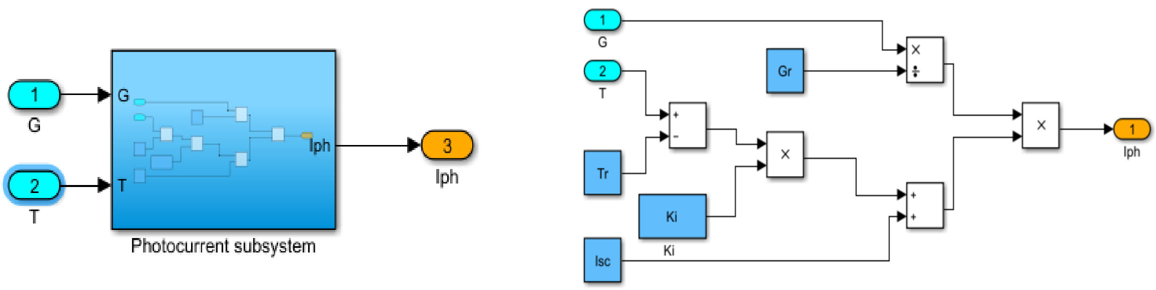


Figure 4: Photocurrent model

2.2. PV reverse saturation current model

This block represents the diode reverse saturation current based on equation (8) as shown in figure 5.The inputs are short circuit current (A) and operating temperature (Kelvin) and the output is the diode reverse saturation current (A), the parameters used in this block is electron charge, voltage across the output terminal, number of series cells, Boltzman'n constant and diode ideality factor [13] [14]

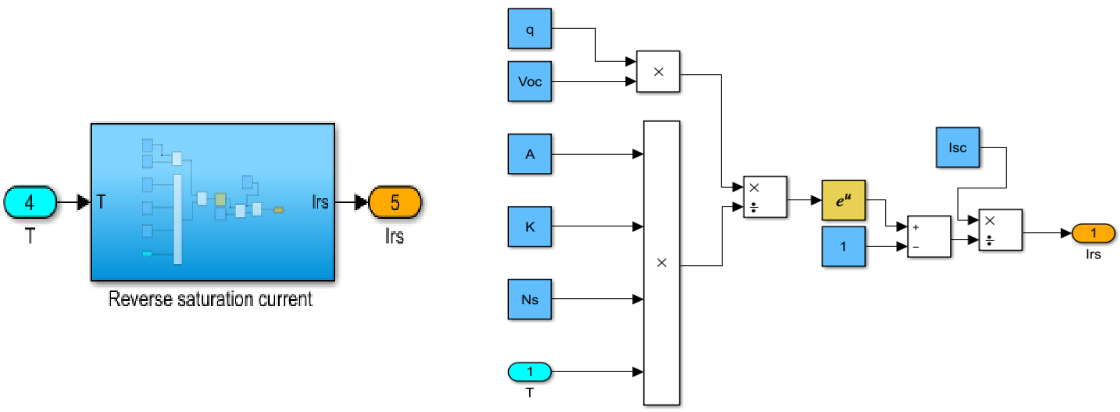


Figure 5: Reverse saturation current model

2.3. PV saturation current model

Equation (6) represents saturation current (I0), which varies with the cell temperature and the model for same is prepared in the Simulink environment. The saturation current subsystem model as shown in Figure 6 is used as inputs along with energy bandgap, electron charge, reference temperature and operating temperature of module.

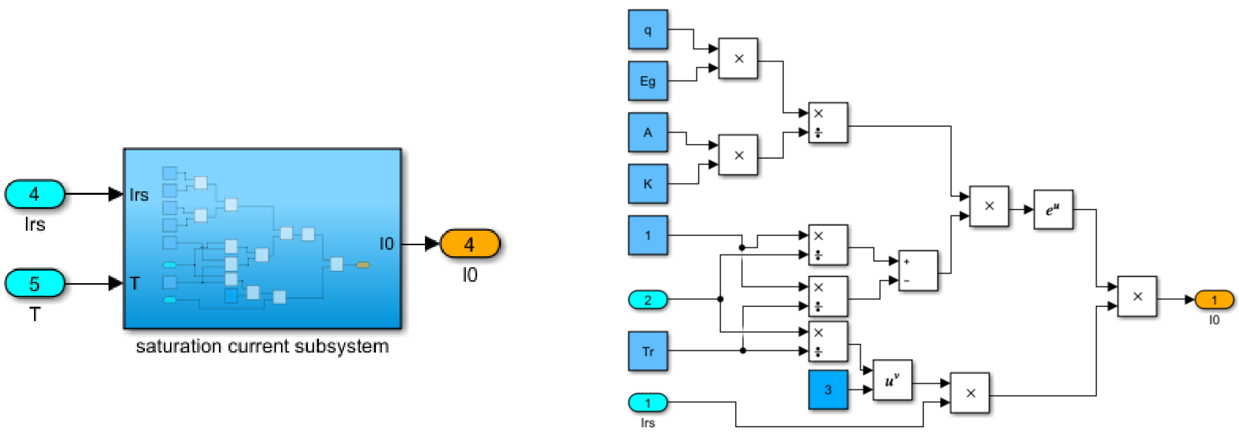


Figure 6: Saturation current model

2.4. PV output current model

Output current is given by Eq (4). It takes temperature (T) in Kelvin, short circuit current (A), Photocell current (A) and voltage across the output terminals (volt) as inputs The parameters used in this block are electron charge, Boltzman'n constant, diode ideality factor, and value of series and shunt resistance. The details of this block shown in figure 7, which is the subsystem of the block.

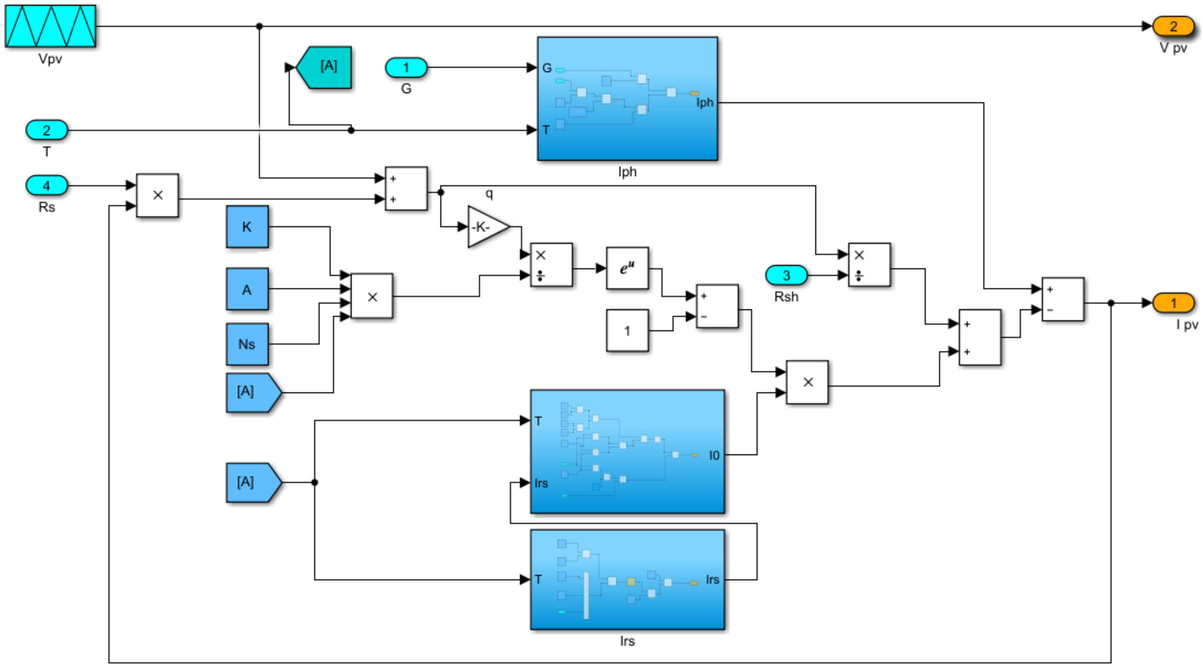


Figure 7: output current model

2.5. Final Solar cell system

The overall system module that simulates the Solar cell system is illustrated in Figure 8 .which consists of irradiance (G) temperature (To), series résistance Rs and shunt resistance rsh as the input parameters and provides output results as current (I) and voltage (V).

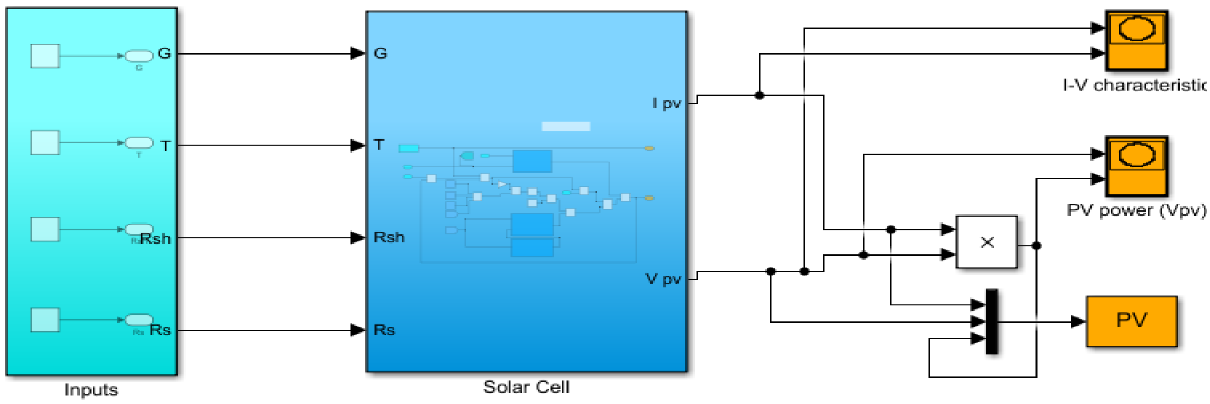


Figure 8: Final Solar cell system

2.7. Array PV model

The figure 9 show a PV array wich consist of 6 modules connected in series and simulated in STC condition (G=1000 W/m² and T=25 °C) thes results of I_V and P_V characteristics are illustrated in figure 11 .

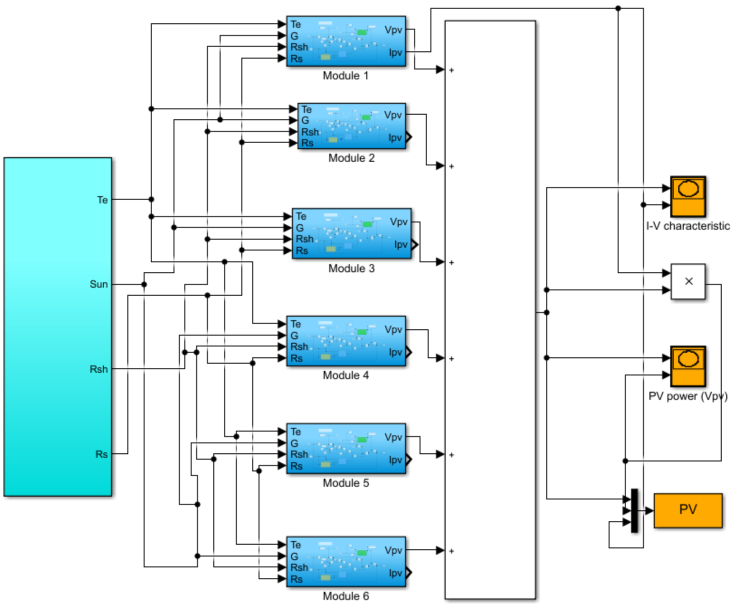


Figure 9: Array PV simulation

3. Simulation results and discussion

Due to the previously discussed mathematical equations. modeling of PV solar cell is developed under Matlab simulink. MSX-60W PV panel module parameters from manufacturer datasheet are incorporated during simulation block model and consider as reference module. The final Solar PV solar cell as depicted in Figure 8 are simulated and obtained output results as current, voltage and power, due to the variation of radiation and temperature as input parameters [14]

3.1. Simulation resuls in standard test conditions

The "peak power" is a normative data used to characterize the photovoltaic cells and modules, measured during a test carried out in laboratory, under an irradiation of 1000 W/m² and at a temperature of 25°C, the light having the expected spectrum after the crossing of 1.5 times the thickness of the atmosphere (Air Mass 1.5). It corresponds to the power that a cell, a module or a photovoltaic field can deliver under these standard conditions (STC). Simulation of the solar PV model executes the I–V and P–V characteristics curves as illustrated in figure 10. Generally a good agreement was observed between various performance parameters results of reference model and simulated PV model at STC condition.

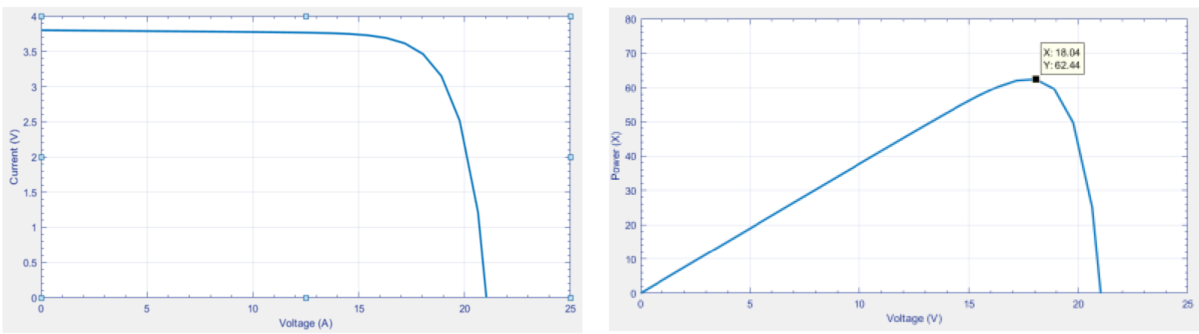


Figure 10: I-V and P-V caracteristics for MSX-60W panel at STC conditions

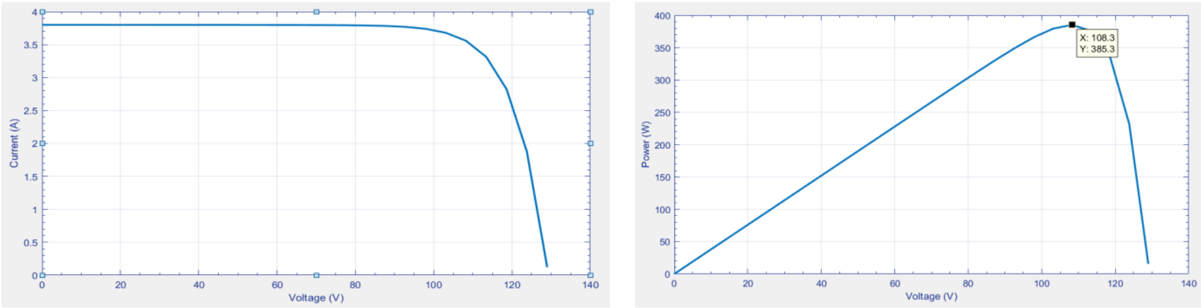


Figure 11: I-V and P-V caracteristics for PV array (6 panels connected in serie)

3.2. Irradiance effects on PV solar cell

By varying the intensity of irradiance from 400 W/m² to 1000 W/m² at constant temperature of 25 °C , The effect on solar PV cell I–V and P–V characteristics curves are depicted in Figure 12. It is observed that curren depends strongly on the solar irradiation . However, the voltage increases by 0.05 V when the solar irradiation has increased from 400 W/m² to 1000 W /m²

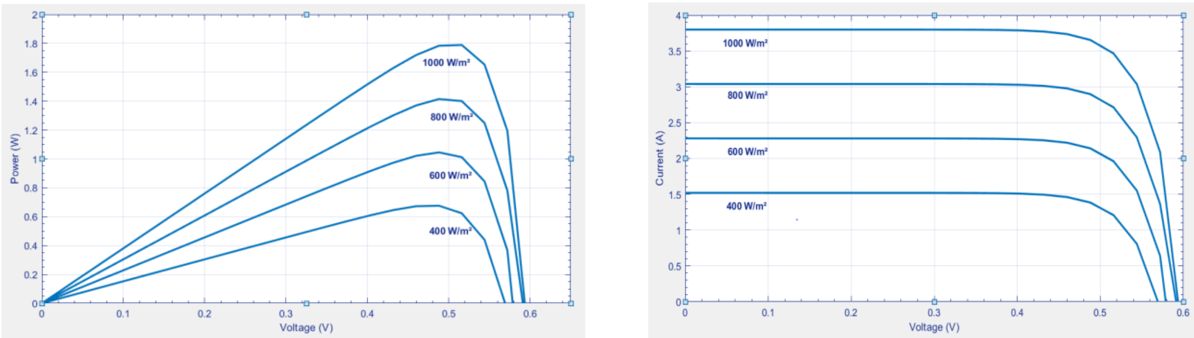


Figure 12: I–V and P-V characteristics, varying irradiance at constant temperature

3.3. Temperature effect on PV solar module

In general, when irradiance intensity is kept constant at 1000 W/m², whilethe temperature varies from 0 °C to 75 °C, the open circuit voltage Voc, decreases slightly, while the short circuit current short-circuit current increases as illustrated in figure 13.

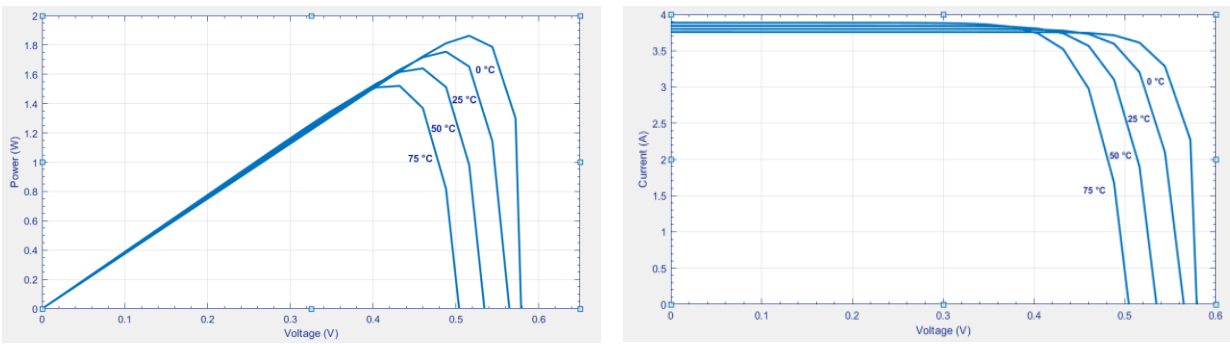


Figure 13: I–V and P-V characteristics, varying temperature at constant solar radiation.

3.3 Rs effect on PV solar module

The value of the series resistance is very small, and in some cases it can be neglected. However, to make the model suitable for any given PV module, it is possible to vary this resistance and predict the influence of its variation on the PV module outputs. As can be seen in figure 14 the variation of Rs affects the angle of the I-V curve, resulting in a deviation of the slope of the maximum power point The simulation was performed for three different values of Rs,. 1mΩ, 4mΩ and 8mΩ. We have shown that higher values of Rs reduce the output power. The fill factor, given by equation. (5), decreases as Rs increases.

$$FF = \frac{\mathrm{P}_{\max}}{Voc\mathrm{I}_{\mathrm{sc}}}$$

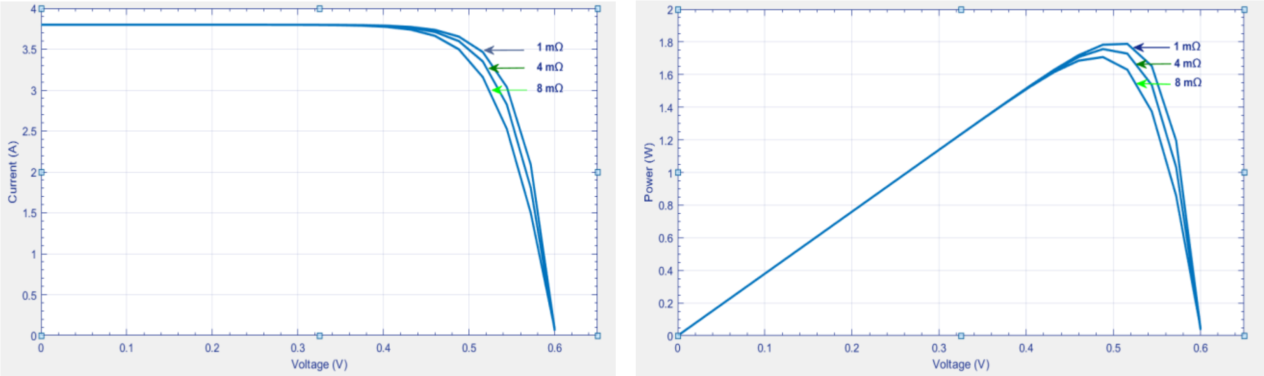


Figure 14: I–V and P-V characteristics, varying serie résistance

3.4. Rsh effect on PV solar module

Figure 15 shows that The shunt resistance must be large enough for a better power output and a good fill factor. Indeed, for a low shunt resistance, the current drops more strongly which means that the power loss is high and the fill factor is low

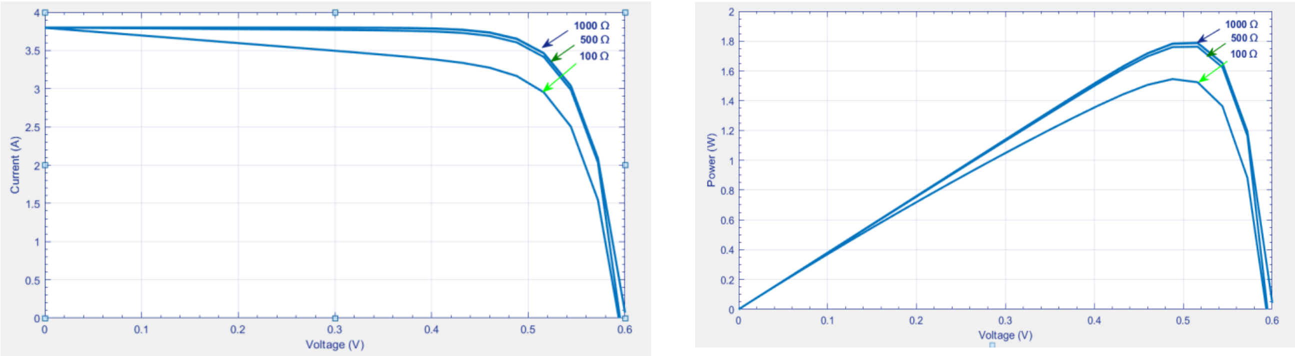


Figure 15 : characteristics, varying shunt résistance.

3.5. Reverse saturation current effect on PV solar module

The model gives the possibility to know the behavior of the photovoltaic module for different reverse saturation currents of the diode. The curves in figure 16 have been plotted for three different values of Irs: 100nA, 10nA 1nA. The influence of an increase of Irs is obviously considered as the as the decrease of the open circuit voltage Voc

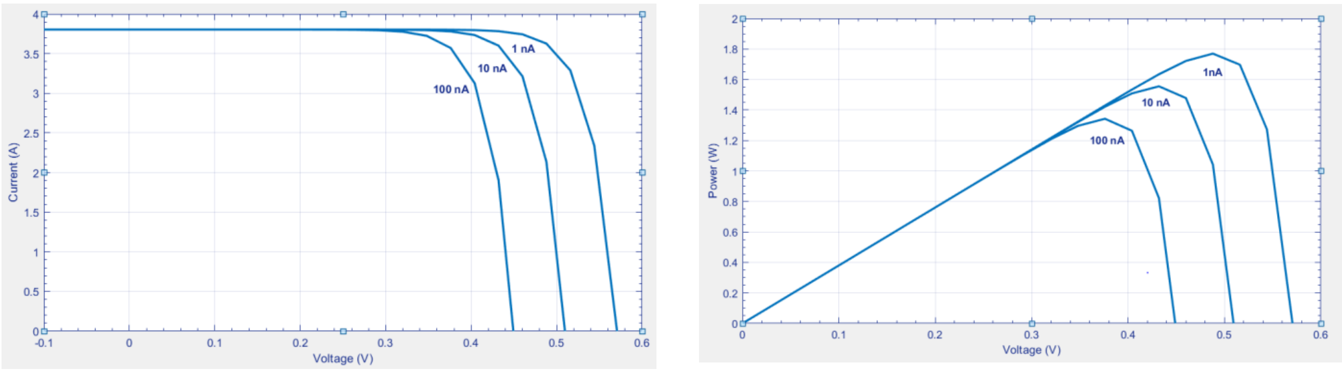


Figure 16: I–V and P-V characteristics, varying reverse saturation current

4. Modelling of PV array under partial shading

Adding up the voltages in the case of a series assembly of PV cells is easy if all the cells are identical and work under the same sunlight and temperature conditions. But, in real operating conditions, if the cells are slightly different or not uniformly illuminated, the electrical behavior is not easily predictable and depends on the characteristics of each cell and the illumination conditions [15] [16].

To remedy this phenomenon, 4 photovoltaic panels are connected in series with by-pass diodes whose role is to protect the cells, which become passive (Figure.8). When the bypass diode starts working, it short-circuits the panel, thus avoiding the circulation of reverse currents within the cells. On the other hand, this effective solution reduces the power delivered and the voltage at the panel terminals. The degradation of a single cell in a series grouping therefore condemns the group of cells protected by the bypass diode to produce no power.

4.1. Series configuration

In the case of a combination of four panels in series, the first of which is subjected to direct illumination, and the others subjected to several levels of illumination as illustrates in figure 17

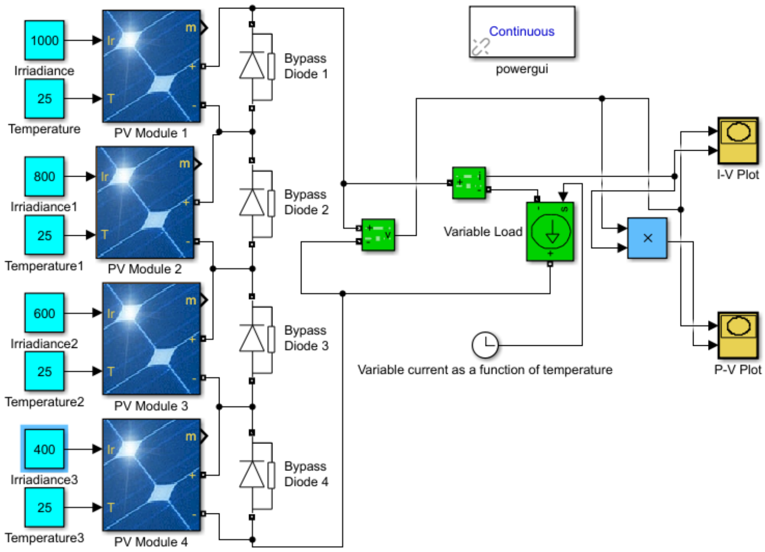
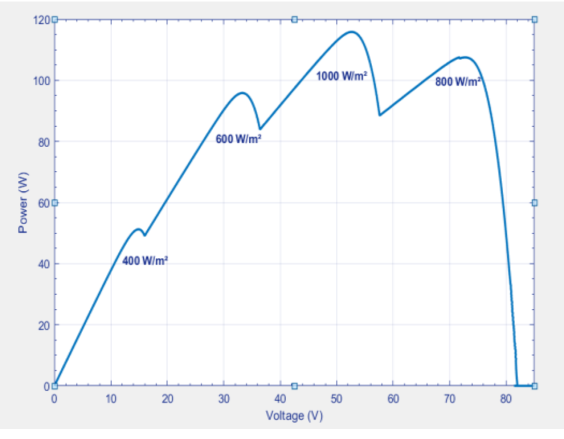


Figure 17 : four module connected in serie with bypass diode

The simulation results of I_V and P_V characteristics under four different irradiance as follows: G1 = 1000 W/m², G2 = 800 W/m², G3 = 600 W/m², G4 = 400 W/m² are shown in figure 18 :



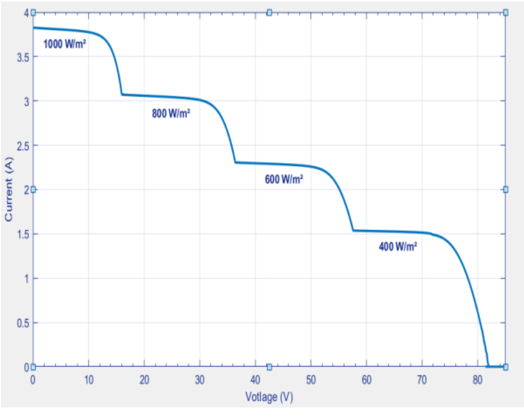


Figure 18 : I–V and P–V characteristics - 4 modules in series

4.1. Series_parallel configuration

Another PV array is taken into consideration, wich represents the assembly of two parallel paths, and each parallel connection with two modules connected in series as shown in Figure 19. Each of two PV modules is controlled by their own input of irradiance.

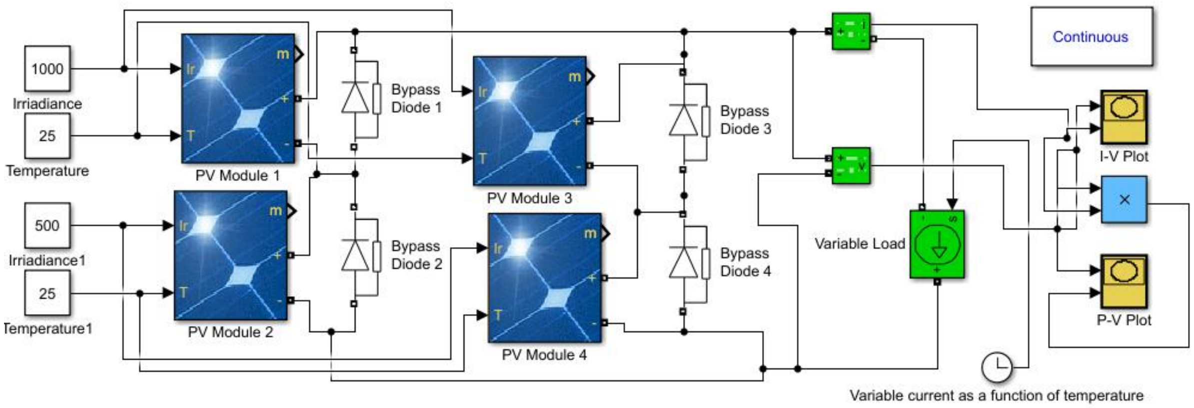


Figure 19 : four module connected in serie_parallel with bypass diode

The four modules are subjected to different weather conditions (1000 W/m² and 500 W/m²) and a constant temperature (25 °C). as illustrated in figure 20 There are two power peaks with two different irradiance values.

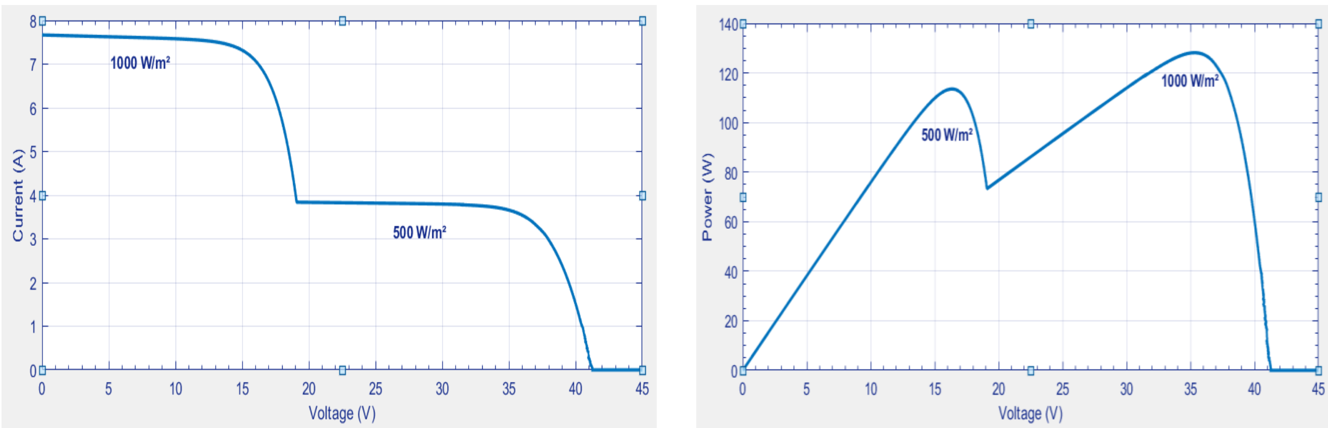


Figure 20 : I–V and P–V characteristics - serie_parallel configuration

Conclustion

The analog and mathematical modeling of a one-diode photovoltaic generator with two series and shunt resistors was the main part of our work in this paper which allowed us to start the simulation part under Matlab /simukink with a more objective methodology. The simulation results show the influence of the parameters that come into play in the performance of solar power systems such as the irradiation solar, temperature, series resistance Rs, shunt resistance...) . The extraction of the maximum power produced by the PV or the MPPT (maximum power point traking) model of the photovoltaic generator presented is reinforced by other control and regulation components (power electronic block, tracking power electronic block, tracking system...etc.). The external characteristic of a PV array under inhomogeneous lighting conditions is distorted, it has several maximum power points, the largest is the global power point (GMPP) and the others are local power points (LMPP). The shading phenomenon can significantly limit the performance of the installed PV pumping system. To reduce the effect of shading on a PV system, it is necessary to establish proper control to ensure operation at the global power point (GMPP) under all conditions.

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