

Simulink Model of Solar Array for Photovoltaic Power Generation System

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Abstract

Photovoltaic power supplied to the utility grid is gaining more and more visibility while the world's powers demand is increases. Growing demand, advancements in semiconductor technology and magnetic materials such as high frequency inductor cores, has a significant impact on PV inverter topologies and their efficiencies, on the improvement of the control circuits on the potential of costs reduction. The user naturally wants to operate the Photovoltaic (PV) array at its highest energy conversion output by continuously utilizing the maximum available solar power of the array. In this paper, a comprehensive but straightforward solar cell model is introduced which focuses on a MATLAB/SIMULINK model of a photovoltaic cell. This model is based on mathematical equations and is described through an equivalent circuit including a photocurrent source, a diode, a series resistor and a shunt resistor. The developed model allows the prediction of PV cell behaviour under different physical and environmental parameters. Simulation results are given for validating the proposed model.

Keywords: Matlab software, Solar cell model, photovoltaic energy.

1. Introduction

Nowadays there is a growing concern regarding the effects of fossil fuels in the environment, solar cell panels have become more and more popular since solar energy is renewable and widely available. Various experiments are carried out to study the effects of changing operating parameters in terms of the solar cell performance. A Matlab/Simulink solar cell model that behaves accurately under a variety of situations is developed and discussed in this paper.

A PV system directly converts sunlight into electricity. Power electronic converters are usually required to process the electricity from the PV device. These converters may be used to regulate the voltage and current at the load, to control the power flow in grid-connected systems, and for the maximum power point tracking (MPPT) of the device [1].

The electrical energy produced by a solar cell at any time instant depends on its intrinsic properties and the incoming solar radiation [2]. The solar radiation is composed of photons of different energies, and some are absorbed at the $p-n$ junction. Photons with energies lower than the band gap of the solar cell are useless and generate no voltage or electric current. Photons with energy superior to the band gap generate electricity, but only the energy corresponding to the band gap is used. The remainder of energy is dissipated as heat in the body of the solar cell [3]. The paper uses the equivalent circuit of a solar cell with its parameters as a tool to simulate in order to consider the irradiance and temperature changes, in the P-V & I-V characteristics of PV cell.

2. Modeling of Solar Cell

2.1. Ideal Solar Cell

As mentioned previously, the solar cells are semiconductor with a $p-n$ junction fabricated in a thin wafer or layer of semiconductors. When exposed to light a photo current proportional to the solar radiation is generated, if the photon energy is greater than the band gap. In the dark, the I-V characteristics of a solar cell have an exponential characteristic similar to that of a diode [4]. In order to maximize the extracted output power from a PV power plant with the help of MPPT control, the understanding and modelling of PV cell is necessary [5].

The ideal equivalent circuit of a solar cell is a current source in parallel with a single-diode. The configuration of the simulated ideal solar cell with single-diode is shown in Fig. 1.

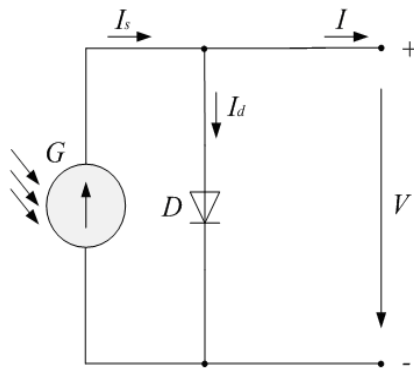


Fig. 1: Ideal solar cell with single-diode.

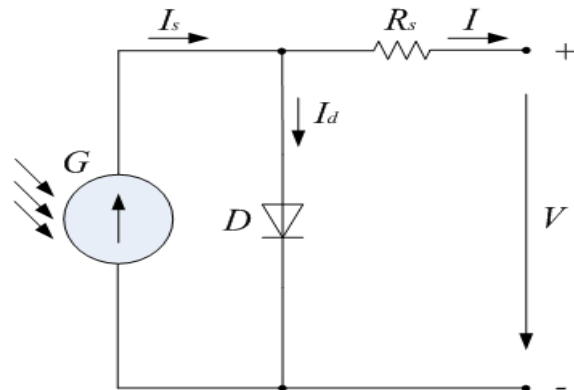


Fig. 2: Solar cell with single-diode and series resistance

In Fig. 1, G is the solar radiance, I_s is the photo generated current, I_d is the diode current, I is the output current, and V is the terminal voltage. The I-V characteristics of the ideal solar cell with single diode are given by:

$$I = I_s - I_0 \left(e^{\frac{qV_d}{mkT}} - 1 \right) \quad (1)$$

Where, I_0 is the diode reverse bias saturation current, q is the electron charge, m is the diode ideality factor, k is the Boltzman's constant, and T is the cell temperature.

A solar cell can be at least characterised by the short circuit current I_{sc} , the open circuit voltage V_{oc} , and the diode ideality factor m .

For the same irradiance and $p-n$ junction temperature conditions, the short circuit current I_{sc} it is the greatest value of the current generated by the cell. The short circuit current I_{sc} is given by:

$$I_{sc} = I = I_s \text{ for } V=0 \quad (2)$$

For the same irradiance and $p-n$ junction temperature conditions, the open circuit voltage V_{oc} is the greatest value of the voltage at the cell terminals [7].

The open circuit voltage V_{oc} is given by:

$$V_{oc} = \frac{mkT}{q} \ln \left(\frac{I_{sc} + I_0}{I_0} \right) \quad (3)$$

2.2 Solar Cell with Series Resistance

More accuracy can be introduced to the model by adding a series resistance. The configuration of the simulated solar cell with single-diode and series resistance is shown above in Fig. 2.

The I-V characteristics of the solar cell with single-diode and series resistance are given by:

$$I = I_s - I_0 \left(e^{\frac{q(V+IR_s)}{mkT}} - 1 \right) \quad (4)$$

For the same irradiance and $p-n$ junction temperature conditions, the inclusion of a series resistance in the model implies the use of a current equation to determine the output current in function of the terminal voltage.

The short circuit current I_{sc} is given by:

$$I_{sc} = I = I_s - I_0 \left(e^{\frac{q(I_{sc}R_s)}{mkT}} - 1 \right) \text{ for } V=0 \quad (5)$$

Normally the series resistance is small .Hence, the open circuit voltage V_{oc} is same as in eq. (3) for $I=0$.

3. Simulation

The SIMULINK model equation for determining the diode reverse saturation current at the reference temperature which given by:

$$I_o = \frac{I_{sc,n} + K_i \Delta T}{\exp\left(\frac{V_{oc,n} + K_v \Delta T}{m V_t}\right) - 1} \quad (6)$$

Where 'n' in all equations is for nominal condition K_i (usually 25°C and $1000\text{w}/\text{m}^2$), is the current coefficient, K_v is the voltage coefficient, $\Delta T = T - T_n$ [being T and T_n the actual and nominal temperature (K)].

The SIMULINK model equation for determining the light generated current of the photovoltaic cell which depends linearly on the influence of temperature and solar radiation as given by:

$$I_{sc} = (I_{sc,n} + K_i \Delta T) \frac{G}{G_n} \quad (7)$$

Fig. 3 shows the SIMULINK model for determining the model current, which has given by:

$$I_m = I_{sc} N_{pp} - I_o N_{pp} \left[\exp\left(\frac{V + I \left(\frac{N_{ss}}{N_{pp}}\right) R_s}{m V_t N_{ss}}\right) - 1 \right] \quad (8)$$

Where I_m -model current (A), N_{ss} - no. of series connected module, N_{pp} -no. of parallel connected module, V_t - thermal potential of PV array(V).

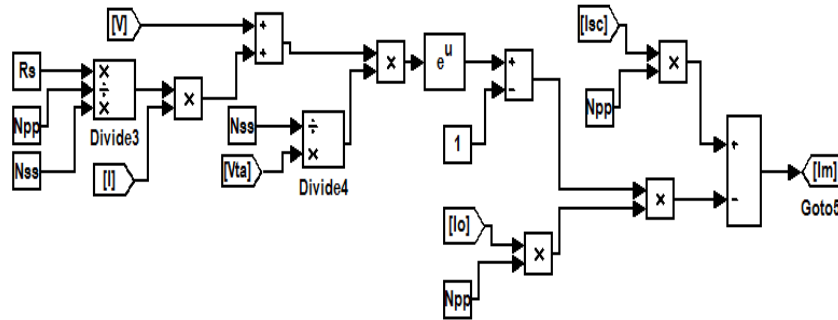


Fig. 3: SIMULINK model for I_m

4. Results and Discussions

In reality, many factors could affect the performance of solar cells. Those parameters are not constant but changing all the time. Solar cells are usually studied under changing conditions including changing temperatures and irradiances. In this section, a reference PV curve and a reference IV curve are presented. Then scenarios of different changing parameters are analyzed.

4.1. Effects of Changing Temperature

For all the simulations presented in this paper, a set of reference input parameters are used to generate a reference PV curve and a reference IV curve. The reference PV curve and IV curve are used to be compared with cases in which one of the parameters is different. The reference input parameters are as $V_{oc,n}=32.9$ (V), $I_{sc,n} =8.21$ (A), $K_i=0.0032(A/K)$, $K_v=0.1230$ (A/K), $N_s=54$, $N_{ss}=1$, $N_{pp}=1$, $R_s=0.221$ (Ω), $R_p=415.405$ (Ω), $I_{mp}=7.61$ (A), $V_{mp}=26.3$ (V), and $m=1.3$.

The reference PV and IV curves (in red color) are compared with the PV and IV curves with a temperature of 50 °C and 75°C as shown in Fig. 4.

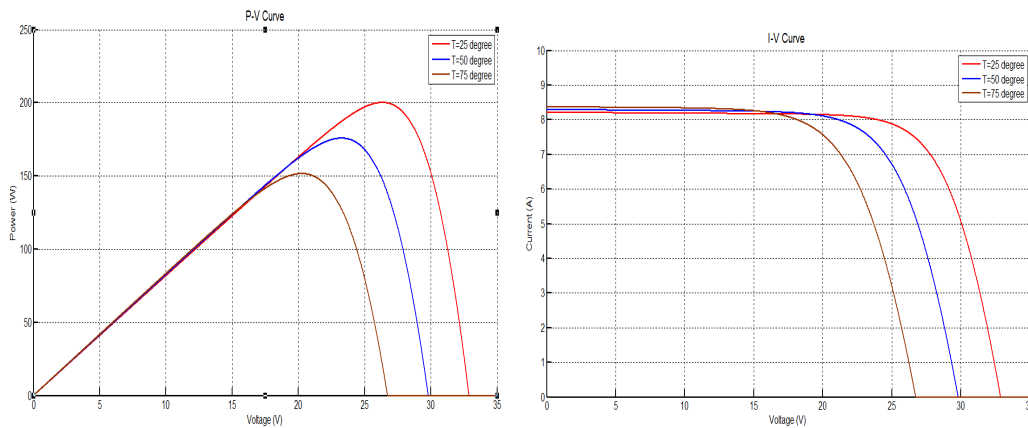


Fig. 4: Effects of changing the temperature.

From the comparison, it is seen that an increase in temperature leads to decrease in the open circuit voltage and a slight decrease in the short circuit current.

4.2. Effects of Changing irradiation

In the following PV and IV curves in Fig.5, the reference PV and IV curves are compared with the PV and IV curves with an irradiance of 1200 W/m² and 1400W/m².

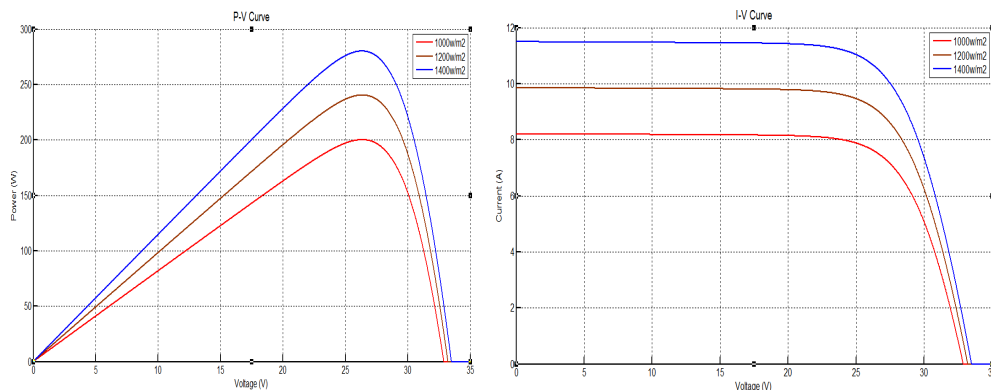


Fig. 5: Effects of Changing irradiation

From the comparison, it is seen that an increase in the irradiance leads to a small increase in the open circuit voltage and a large increase in the short circuit current.

4.3. Effects of Series Resistance Changes

In the following PV and IV curves in Fig.6, the reference PV and IV curves are compared with the PV and IV curves with a series resistance of 0.400Ω .

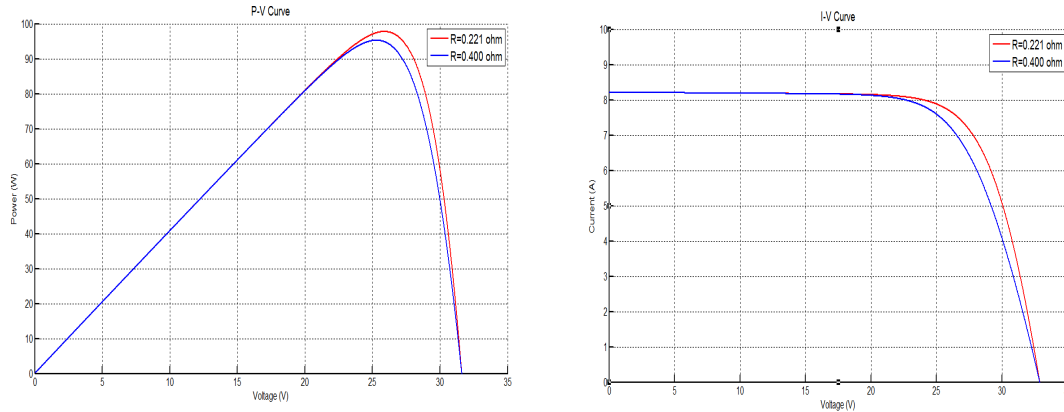


Fig. 6: Effects of changing the Series Resistance.

From the comparison, it is seen that an increase in the series resistance causes an inward bending at the corners of both the IV and PV curves with no change in I_{sc} or V_{oc} .

5. Conclusion

This paper presents a new solar cell model using Matlab/Simulink mathematical operation blocks. This model is based on the fundamental circuit equations of a solar PV cell taking into account the effects of physical and environmental parameters such as the solar radiation, cell temperature, series resistance, shunt resistance and number of series cell, in terms of the PV and IV curve. The model has excellent accuracy in generating the PV and IV curves. Moreover this model could be built with any general purpose simulation software.

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