MATLAB/SIMULINK MODEL FOR SIMULATION OF PHOTOVOLTAIC MODULE

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Abstract

This paper introduces a circuit-based simulation model for a Photovoltaic (PV) cell in order to estimate the electrical behavior of the cell with respect to changes on environmental parameter of temperature and irradiance. An accurate PV module electrical model is presented based on the Shockley diode equation. The model was developed using MATLAB/SIMULINK, a simulation program that provides graphical interface for building models as modular block diagrams, and accepts irradiance and temperature as variable parameters and outputs the I-V characteristic. A particular typical 80W solar panel was used to evaluate the model, and the results were compare with manufacturer's published curves and showed excellent correspondence to the model.

I. Introduction

Renewable energy generation offers great potential in meeting future global energy requirements. The production of power from renewable energies will lead to a significant reduction in the environmental pollution in comparison with the production by fossil fuels. The renewed attention for this energy source is motivated by advances in technology, environmental concerns and a growing energy demand. Solar power is a renewable energy source that has great potential when compared to other renewable energies and might one day soon replace fossil fuel dependent energy sources. However, for that to happen, solar power cost per kilowatt-hour has to be competitive with fossil fuel energy sources. Currently, solar panels are not very efficient with only about 17% efficiency in their ability to convert sunlight to electrical power [1]. The efficiency can drop further due to other factors such as solar panel temperature and load conditions. In order to maximize the power derived from the solar panel it is important to operate the panel at its optimal power point. To extract maximum power from a PV array, a maximum power point tracking (MPPT) controller is used. Many MPPT methods have been reported in literature [2]. A photovoltaic (PV) system consists of solar panels that generate electricity by the direct conversion of the sun's energy into electricity. PV cells operate on the principles of the photovoltaic effect; sunlight is composed of photons, each containing a different amount of energy (depending on the wavelength). When a photon striking a PV cell is absorbed its energy is transferred to an electron which now has the sufficient energy to escape its previous position. This movement of electrons generates a current thus converting sunlight to electrical energy. When the irradiance or light intensity is low, the flux of photon is less than when the sun is bright and the light intensity is high, thus more current is generated as the light intensity increases. It is found that the change in voltage is minimal with varying irradiance and for most practical application; the change is considered negligible [3]. Although irradiance is an important factor in determining the I-V characteristic of a solar panel, it is not the only factor. Temperature also plays an important role in predicting the I-V characteristic, and the effects of both factors have to be considered when designing a PV system, since the irradiance mainly affects the output current, and the temperature mainly affects the terminal voltage. This work presents the development of MATLAB/SIMULINK model for simulation of photovoltaic module. A typical 80W solar panel is used to evaluate the model, and the results are compare with manufacturer's published curves [4] and showed excellent correspondence to the model.

II. Photovoltaic generator

A photovoltaic generator is a device which converts energy in the form of solar radiation to energy in the form of electric current. The basic component of a PV system is the photovoltaic cell. Multiple cells are connected in series and parallel to form solar panels or modules. Solar modules are connected in series and parallel in order to create a PV array. Solar cells consist of a p-n junction fabricated in a thin layer of semiconductor. The semiconductor electrons can be located in either the valence band or conduction band. Initially, all the electrons in the semiconductor fill up the valence band [5]. When solar energy (photons) hits the solar cell, with energy greater than band gap energy of the semiconductor, electrons are knocked loose from the atoms in the material, creating electron-hole pairs [6]. These carriers are swept apart under the influence of the internal electric fields of the p-n junction and create a current proportional to the incident radiation. When the cell is short circuited, this current flows in the external circuit; when open circuited, this current is shunted internally by the intrinsic p-n junction diode. In the dark, the I-V output characteristic of a solar cell has an exponential characteristic similar to that of a diode. The characteristic of this diode therefore sets the open circuit voltage characteristics of the cell [6]. The amount of energy from sunlight (photons) that is absorbed by a solar cell determines its efficiency. A photon can be reflected, absorbed or it can pass through a semiconductor [7]. Since only the photons that are absorbed contribute to the electrical energy, it is important to reduce the percentage of photons that pass through and that are reflected. An anti-reflective coating is usually applied to the surface of the solar cell to decrease the number of photons that are reflected. This reduces the percentage of photons that are reflected but some photons are still able to pass right through the semiconductor material. The photons in sunlight have a wide range of wavelengths, and some photons at certain wavelengths are able to pass through the semiconductor material. One of the major tasks in controlling photovoltaic cells for power generation is improving cell efficiency and maximizing energy extraction. This requires I-V (current-to-voltage) measurements to characterize performance and determine the load impedance that best matches the cell's source impedance. The best match can then be determined on a point on the I-V curve of the solar cell.

III. Modeling of Solar-Cell

The photovoltaic (PV) generator model is usually based on the electrical characteristics, i.e., the voltage current relationship, of the cell under various levels of radiation and at different cell temperature. The simplest equivalent circuit of a solar cell is a current source in parallel with a diode. The output of the current source is directly proportional to the light falling on the cell photocurrent (Iph). During darkness, the solar cell is not an active device; it works as a diode, i.e. a p-n junction. It produces neither a current nor a voltage. Thus the mathematical model of the photovoltaic generator is based on an equivalent circuit of a one-diode shown in Fig.1.

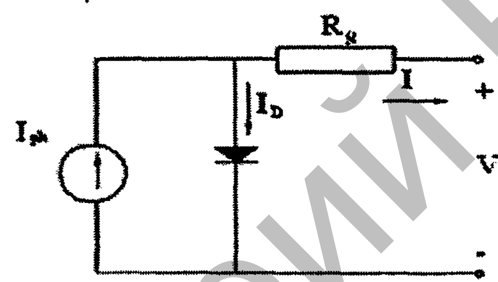

Fig. 1 Model for a single solar cell.

The relationship between the current I and the voltage V of the equivalent circuit can be found by equating the light current Iph, diode current ID, to the operation current I as follows:

$$I = I_{ph} - I_D = I_{ph} - I_{sat}\left[e^{\frac{q(V+IR_S)}{nkT}} - 1\right] \quad (1)$$

Where:

I_{ph} - the light current [A],

I_{sat} - the diode reverse saturation current [A],

Rs - the series resistance [Ω],

V - the operation voltage [V],

I - the operation current [A].

q = charge of one electron ($1.602 \cdot 10^{-19} C$),

n - Diode idealising factor,

k - Boltzman's constant (1.38$\cdot 10^{-23} J/K$)

T=Junction temperature in Kelvin.

The power P produced by the PV generator is given by

$$P = I \cdot V = V \cdot I_{ph} - I_{sat}\left[e^{\frac{q(V+IR_S)}{nkT}} - 1\right] \quad (2)$$

The energy output in the form of current is directly proportional to the energy input in the form of solar irradiation. There is a small temperature coefficient, on the order of a few milliamps per degree Celsius to account for temperature differences recognized empirically.

$$I_{ph} = (G, T) = I_{scs} \cdot \frac{G_a}{G_{as}} + \alpha_{scT}(T - T_s) \quad (3)$$

Where:

I_{scs} – Short circuit current at standard test condition

G_a – Solar irradiance (W/m3)
G_{as} – Solar irradiance at standard test condition (1000W/m3)
α_{scT} – Temperature coefficient of short-circuit current
T - Cell temperature (oC)
T_s – Cell temperature at standard test conditions (25 oC)
The open circuit voltage under given environmental conditions is calculated as follows:

$$V_{oc}(G,T) - V_{ocs} + \beta_{ocT}(T - T_s) + \frac{kT}{q}\ln\left(I_{mpp}/I_{scs}\right) \quad (4)$$

Where:
V_{ocs} – Open-circuit voltage at standard test condition.
β_{ocT} – Temperature coefficient of open-circuit voltage.
I_{mpp} – Current at MPP
Under open circuit condition; $I_{ph}(G,T)=I_D = (G,T)$

But $I_{ph}(G,T)=I_{sat}(G,T)\cdot\left[e^{\frac{V_{oc}}{V_t}} - 1\right]$

Therefore

$$I_{sat}(G,T) = \frac{I_{ph}(G,T)}{\left[e^{\left(e^{\frac{V_{oc}T}{V_tT}}-1\right)} - 1\right]} \quad (5)$$

Where

$$V_t(T) = \frac{AkT}{q} \quad \text{Thermal voltage} \quad (6)$$

IV. MatLab/Simulink Modeling of PV Module

Simulink is a simulation program, which provides a graphical interface for building models as blocks diagram. It offers the advantage of building hierarchical models, namely to have the possibility to view the system at different levels. Simulink provides also the possibility to build modular models, which have the advantage that in this way the models can be easily connected together in order to simulate a certain system. Suchmodels also help system designers to optimise the size of the components of the system. The model of the PV module was implemented using a MATLAB/SIMULINK simulation program. The detailed Simulink implementation of the mathematical model of the PV module, described in previous section is shown in Figure.2 the implicit function of the current I , for the PV module, as it was described in last section can be solved easily by the "algebraic constraint" block from simulink. Fig. 2 shows the blocks that are "hidden" inside the PV block Fig. 3. It represents the subsystem of the detailed simulink implementation of the mathematical model of the PV system as already discussed (equations 1 to 6).

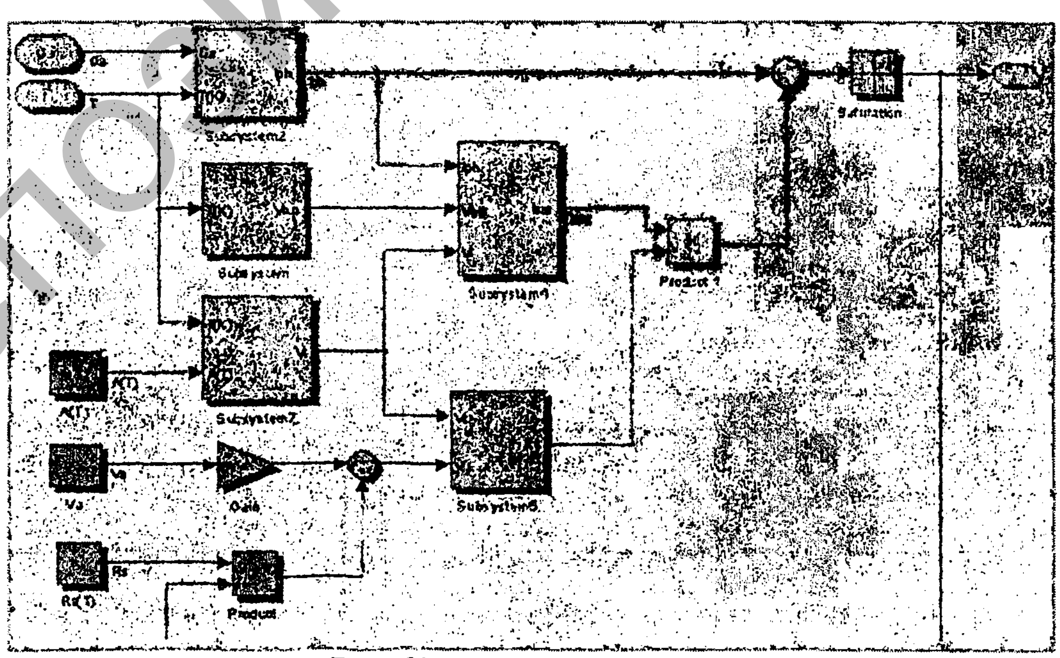

Fig. 2 Simulink PV block diagram.

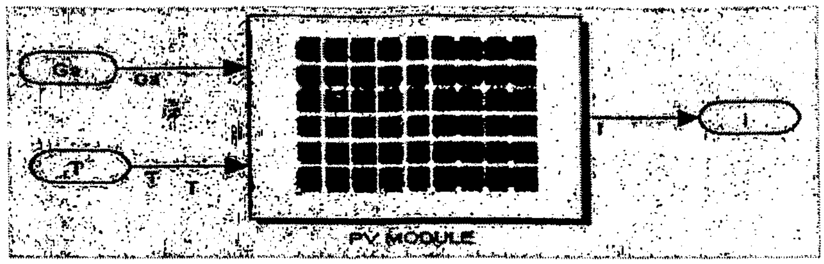

Fig. 3 masked blocks

The Simulink implementation of the PV module, illustrated in Fig. 2, is used to perform a simulation of the PV module for different values of irradiation and cell temperature. Manufacturers of PV arrays usually provide Short circuit current, (Isc), current at MPP (Impp), Open circuit voltage, (Voc), and Voltage at MPP, (Vmpp) at Standard Test Conditions (STC) of 1.5 AM, 1000 W/m2 insulation and 25єC. The key specificationsare shown in Table 1, at Standard Test Condition (STC) (obtained from the PV array datasheet) for an 80W BPSOLAR BP280 PV panel which was used for this simulation.

Table 1: Specifications of the 80W BPSOLAR BP280

Parameter	Value
Maximum Power	80W (+10%/-5%)
Current at MPP, I_{mpp}	4.63 A
Voltage at MPP, V_{mpp}	17.3 V
Short circuit current, I_{sc}	5.16 A
Open circuit voltage,	21.6 V
Coefficient of voltage,	1.57 mA/°C
Coefficient of current,	-78.2 mV/°C

V. Results of MatLab/Simulink Model for Simulation of PV Module

The output of the Matlab/Simulink is shown first for various irradiation levels Fig. 4, and then for various temperatures Fig. 5. Fig. 4 shows how the I-V curve of the PV module is affected by irradiation, when the cell temperature is kept constant (T =25 0C). And Fig.5 shows the influence of the cell temperature on I-V curve, when the irradiation is kept constant (Ga =1000W/m2). The simulation results showed that an increase in irradiance generally caused an increase in the module's output current while an increase in operating temperature generally caused a drop in the module's terminal voltage. In fact, the results showed a linear relationship between the short circuit current and the irradiance level while there is a logarithmic relationship between the open circuit voltage and the operating temperature. Therefore it would seem that the output voltage should increase as the irradiation level increases. However this is not necessarily so, since the cell temperature is likely to rise as the irradiation level increases. An increase in cell temperature will generally lead to a reduction of the output voltage. This makes it imperative to consider the effect of temperature on the cell output voltage as illustrated in Fig. 5. Overall, there is a reduction of the voltage at higher irradiances due to the accompanying higher cell temperature.

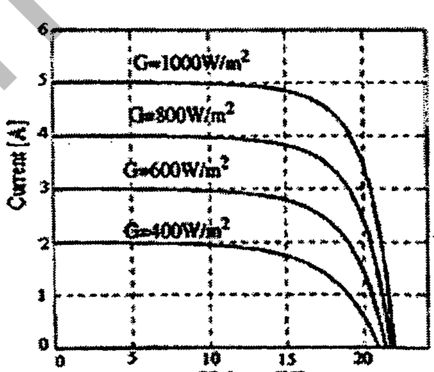

Fig. 4 I-V characteristics at constant solar cell temperature

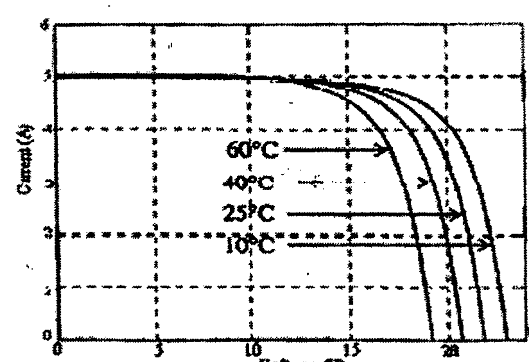

Fig. 5 I-V characteristics-constant Irradiance

A reduction in the terminal voltage or current will lead to a decrease in the output power since both the voltage and current are directly proportional to the output power,. The effect of irradiance and temperature on the output power of the solar cell is shown in Fig. 6 and Fig. 7. The effect of decreasing irradiation level is demonstrated. It mostly affects the module's current and has only a slight effect on the module's voltage. The effect is greater on the module's current since the current decreases linearly with decreasing irradiance while the module's voltage only decrease logarithmically with decreasing irradiance. It is also observed that an increase in the operating temperature of the module has a reducing effect on the output voltage. Increasing module temperature causes a reduction of the output voltage and thus the output power of the solar module.

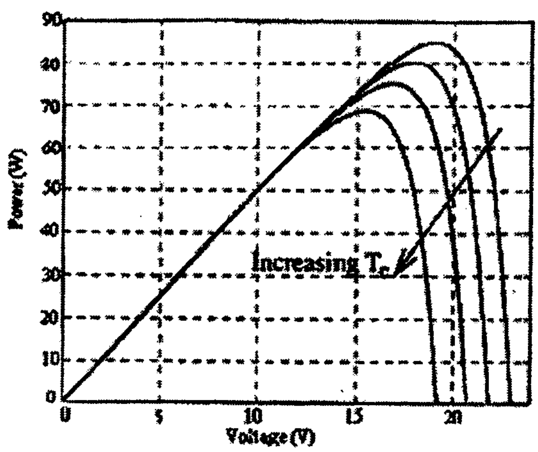

Fig. 6 P-V characteristics at constant irradiance

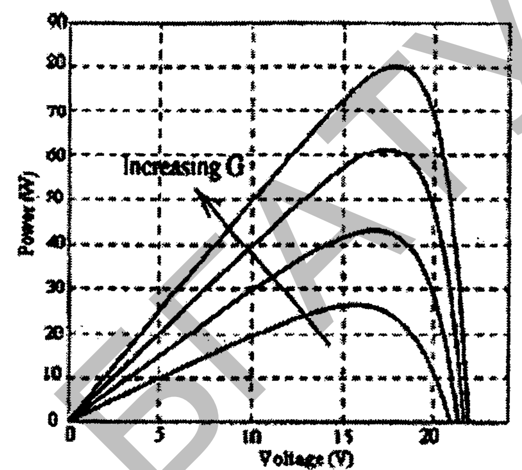

Fig. 7 P-V characteristics at constant Irradiance

VI. Conclusion

This paper has briefly described an accurate PV module electrical model which is developed and demonstrated in Matlab/Simulink for a typical 80W solar panel. Given solar insolation and temperature, the model can be used to calculate the current for a given voltage. The results from the Matlab/Simulink model show excellent correspondence to manufacturer's published curves. Finally the model development was used to show the effect of insolation, and temperature. This paper lays the foundation to develop a complete Matlab/Simulink simulation of solar energy storage system and Reverse-Osmosis Desalination of Seawater powered by solar energy. The final objective is to develop a general model to simulate the electrical behaviour of the PV systems for solar energy applications such as Energy Storage and Reverse-Osmosis Desalination of Seawater.

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