

MATLAB/SIMELECTRONICS Models Based Study of Solar Cells

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Received: 10.10.2012 Accepted: 10.12.2012

Abstract-A Simulation model for simulation of a single solar cell and two solar cells in series has been developed using Simelectronics (Matlab/Simulink) environment and is presented here in this paper. A solar cell block is available in simelectronics, which was used with many other blocks to plot I-V and P-V characteristics under variations of parameters considering one parameter variation at a time. The effect of variation of parameters such as series resistance, R_s , shunt resistance R_{sh} , diode parameters: diode saturation current, I_s and ideality factor, N , could be seen on the characteristics of a single solar cell. Effect of two environmental parameters of temperature and irradiance variations could also be observed from simulated characteristics. Matlab coding has been done to find the maximum power output, P_m , and voltage at maximum power output, V_m , of a single solar cell and two solar cells (in series) under different values of parameters. The P_m and V_m values are tabulated here in this paper for variation of one parameter at a time, considering the diode parameters: I_s and N , resistances: series and shunt, temperature and irradiance.

Keywords-Photovoltaic (PV) Cell, Maximum Power (P_m), Maximum Power Point (MPP), Voltage at MPP(V_m)

1. Introduction

The research in renewable energy has become an increasingly important topic in the 21st century with the problem of energy crisis becoming more and more aggravated, resulting in increased exploitation and search for new energy resources such as wind, water, geothermal and solar energy around the world. Solar energy is green energy, which is inexhaustible and environment friendly. It is becoming one of the most promising alternatives for conventional energy sources. Due to this, photovoltaic solar energy has been increasingly used to generate electric power from sunshine[1].

Solar cells or Photovoltaic (PV) cells are devices that convert sunlight into electric energy using most likely a silicon(or other material) PN junction. A PV cell is a basic unit that generates voltage in the range of 0.5 to 0.8 volts depending on cell technology used. This small generation is not of much commercial use if these cells are not integrated

and connected together in a module to give the handsome voltage at least to charge a standard battery of 12 volts. Thus what we see physically in a PV system is the commercially available module; which are further connected in series and parallel to form a PV system as per the system requirement of voltage and the current [2].

To experiment with PV cells in the laboratory is a time consuming and costly task. So, to overcome this problem, simulation techniques are used to simulate the behavior of PV cells under different conditions. Several simulation softwares are available nowadays. PSPICE has been used [2,3] for the study of silicon solar cells and modules constructed from such series connected cell- strings. The simple study carried out leads to valuable information that would be useful in the design of PV modules and power supply systems utilizing such PV modules as their basic energy source.

Nema, et al. [2] carried out computer simulation based study of photovoltaics cells/ modules using PSPICE. The

PSPICE is an analog/digital circuit simulator which calculates voltage and current in a circuit under variety of different circumstances. This feature of PSpice is used to simulate a circuit based model for PV cells/ modules and then to conduct behavioral study under varying conditions of solar insolation including shading effect, temperature, diode model parameters, series and shunt resistance etc. The study is very helpful in clearly outlining the principles and the intricacies of PV cells/modules and may surely be used to verify impact of different topologies and control techniques on the performance of different types of PV system. To put the simulation study on firm footing an experimental verification is also carried out in the laboratory by developing a PC based data acquisition system.

Hybrid simulation model of PV cell/module and system using Matlab/Simulink and Pspice was developed by Jiang, et al [1]. The hybrid simulation model includes the solar PV cells and the converter power stage and can be expanded to add MPPT (maximum power point tracter) control and other functions. The model is able to simulate both the I-V characteristics curves and the P-V characteristics curves of PV modules under uniform shading conditions (USC) and partial shading conditions (PSC). The model is used to study different parameters variations effects on the PV array.

In the present paper, Simulation model for the solar cell is developed using Simelectronics (Matlab/Simulink) environment . The paper deals with the simulation study of one solar cell and two solar cells connected in series.

2. Simelectronics

SimElectronics® software works with Simscape™ software and extends the physical modeling capabilities of the Simulink® product family with tools for modeling and simulating electromechanical and electronic systems. It contains blocks that let one model electromechanical and electronic systems at a speed and level of fidelity that is appropriate for system-level analysis. The blocks let one perform tradeoff analyses to optimize system design, for example, by testing various algorithms with different circuit implementations.

SimElectronics is part of the Simulink Physical Modeling family. Models using SimElectronics are essentially Simscape block diagrams. To build a system-level model with electrical blocks, a combination of SimElectronics blocks and other Simscape and Simulink blocks can be used.

2.1. Solar Cell Model

The most important component that affects the accuracy of the simulation is the PV cell model. Modeling of PV cell involves the estimation of the I-V and P-V characteristics curves to emulate the real cell under various environmental conditions. The most popular approach is to utilize the electrical equivalent circuit, which is primarily based on diode.

The Solar Cell block in SimElectronics, represents a single solar cell as a parallel current source, I_{ph} , an exponential diode, D and a shunt resistance, R_{sh} that are connected in series with a resistance R_s . Fig.1(a) shows the symbol of solar cell in SimElectronics, Fig.1(b) shows the equivalent circuit.

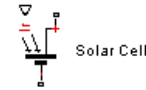


Fig. 1(a) Symbol of a Solar cell

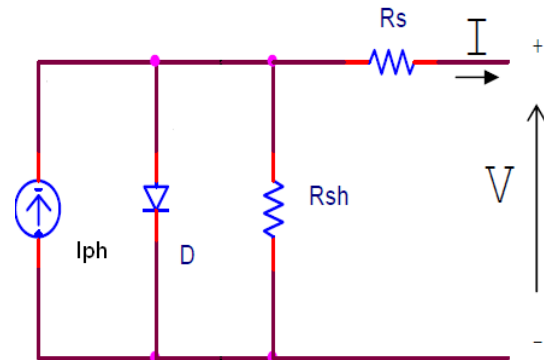


Fig.1(b) Equivalent Circuit of the Solar cell

The output current I is:

$$I = I_{ph} - I_s \left[\exp\left(\frac{V + IR_s}{NV_T}\right) - 1 \right] - \frac{V + IR_s}{R_{sh}}$$

where:

I_{ph} is the solar-induced current:

$$I_{ph} = I_{ph0} \times \frac{I_r}{I_{r0}}, \quad V_T = \frac{kT}{q}$$

I_r is the irradiance (light intensity) in W/m^2 falling on the cell.

I_{ph0} is the measured photo-generated current for the standard irradiance I_{r0} .

I_s is the diode reverse saturation current.

k is the Boltzmann constant.

T is the measurement temperature parameter value.

q is the elementary charge of an electron.

V is the voltage across the solar cell electrical ports.

I is the output current of PV cell.

N is the diode ideality factor.

The Ideality factor varies for amorphous cells, and is typically 1-2 for polycrystalline cells.

This block can be parameterized in terms of the preceding equivalent circuit model parameters or in terms of the short-circuit current and open-circuit voltage the block uses to derive these parameters.

2.2. The Simelectronics Simulation Model for a Solar Cell

The SimElectronics Model used for single solar cell simulation is shown below:

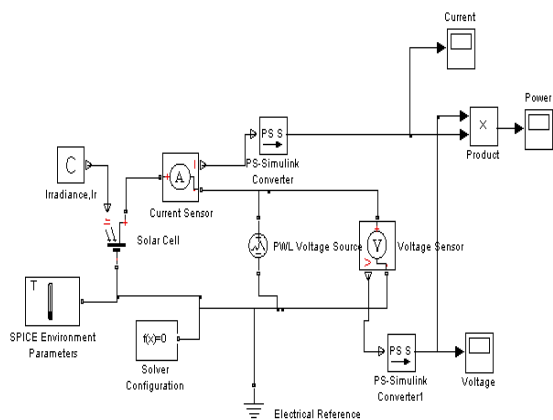


Fig. 2. SimElectronics Simulation Model for a single Cell

This Model was developed using blocks of SimElectronics and Simulink. Solar cell was connected with blocks such as current sensor and voltage sensor to measure the current and voltage across solar cell. Blocks for varying Irradiance level and Temperature, were also connected in the above model. Rest of the blocks were the interface between major blocks and used for plotting I-V characteristics.

The solar cell was parameterized by equivalent circuit parameters. Diode reverse saturation current, I_s , was taken as 0.1nA, measurement temperature was kept as 25°C. Solar-generated current, I_{ph0} , and Irradiance used for measurements, I_{r0} , were kept at their default values of 7.34A and 1000 W/m² respectively.

2.3. Simelectronics Simulation Model For Two Solar Cells In Series

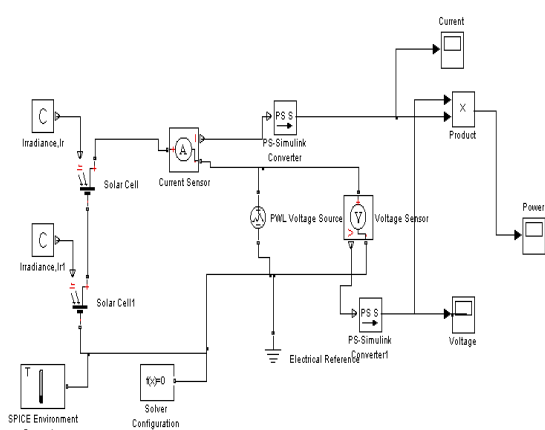


Fig. 3. SimElectronics Simulation Model for Two solar cells in series

Simulations models of Fig.2 and Fig. 3 were used for the simulation of a single solar cell and two solar cells(in series) respectively.

3. The Solar Cell Study

The MATLAB coding was used to simulate the models in Fig. 2 and Fig. 3. In each of the simulations carried out, a set of curves for I-V characteristics and P-V characteristics were obtained for a single solar cell for the variation in one parameter at a time. Next, the values of V_m and P_m are tabulated for both cases for comparison.

3.1. Comparison of P_m and V_m of Single Solar Cell and Two Solar Cells in Series

Matlab coding was done to find the Maximum Power, P_m , and corresponding voltage at maximum power output, V_m , of a single solar cell and two solar cells (in series) under certain values of parameters. The P_m and V_m values are tabulated here in this paper for variation of one parameter at a time, considering the diode parameters: I_s and N , resistances: series and shunt, temperature and irradiance.

Following default values were taken for all the parameters:

- Irradiance (I_r) value was taken as 476.84 W/m² which corresponds to $I_{ph} = 3.5A$ as per the following formula; $I_{ph} = I_{ph0} \times I_r / I_{r0}$.
- The Circuit Temperature (SPICE Environment Parameters) was taken as 25°C.
- The Ideality factor, N was taken as 1.1.
- Diode reverse saturation current, I_s , is taken as 0.1nA.
- R_s was taken as 0.01ohm
- R_{sh} was taken to be 300 ohm

3.1.1. Variation in R_s

The variation of the maximum output power of the cell was investigated for R_s values of 0.01, 0.02, 0.03, 0.04 & 0.05 ohms. Irradiance (I_r) value was taken as 476.84 W/m² which corresponds to $I_{ph} = 3.5A$. The Circuit Temperature (SPICE Environment Parameters) was taken as 25°C. The Ideality factor, N was taken as 1.1. Diode reverse saturation current, I_s , was taken as 0.1nA.

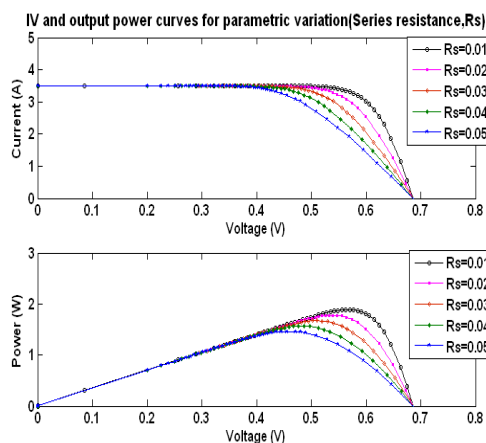


Fig. 3 I-V and P-V curves for parametric variation (Series Resistance, R_s)

Table 1. R_s Variation

R_s (Ω)	No. of cells	0.01	0.02	0.03	0.04	0.05
V_m (V)	1	0.573	0.543	0.514	0.490	0.467
P_m (W)	1	1.902	1.792	1.684	1.577	1.472
V_m (V)	2	1.163	1.105	1.044	0.994	0.932
P_m (W)	2	3.857	3.636	3.420	3.205	2.998

It can be seen that maximum power was obtained at the least value of R_s . As the value of R_s was increased by small increments, the maximum power, P_m and hence V_m decreased, which can be seen from graph, as well as table. In case of single cell, P_m was reduced by approximately 0.1W per 0.01 ohm increase in R_s . For two cells, the decrease in P_m was approx. 0.2W for the same increase in R_s .

3.1.2. Variation in I_s

The effect of variation of I_s on P_m was investigated next. I_s values were varied as 0.1nA, 1nA and 10nA. R_s was fixed at 0.01ohm. Rest of the parameters were kept same as in first investigation. Irradiance (I_r) value was taken as 476.84 W/m^2 . The Circuit Temperature (SPICE Environment Parameters) was taken as 25 °C. The Ideality factor, N was taken as 1.1

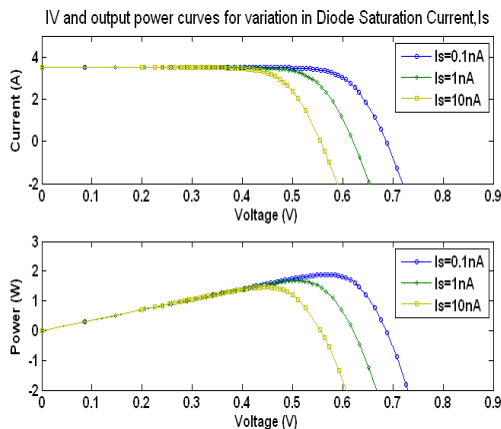


Fig. 4. IV and PV Curves for variation in Diode Saturation Current, I_s

Table 2. I_s Variation

I_s (nA)	No. of cells	0.1	1	10
V_m (V)	1	0.5731	0.5085	0.4533
P_m (W)	1	1.9024	1.6878	1.4745
V_m (V)	2	1.1634	1.0304	0.9128
P_m (W)	2	3.8566	3.4272	3.0020

It can be observed from Fig. 4 and Table 2 that, as I_s increased, V_{oc} (open-circuit voltage, i.e., voltage when current = 0), decreased and hence P_m decreased. P_m was approximately double in case of two solar cells in series, but it was adversely affected by the increase in value of I_s in both cases of single cell and two cells.

3.1.3. Variation in N

I-V and P-V characteristics were simulated for variation in Ideality Factor. R_s was taken as 0.01 ohm, Diode reverse

saturation current, I_s , was taken as 0.1nA. The Circuit temperature (SPICE Environment Parameters) was kept at 25°C. Irradiance (I_r) value was taken as 476.84 W/m^2 . Ideality factor, N was varied as 1.1, 1.3 and 1.5.

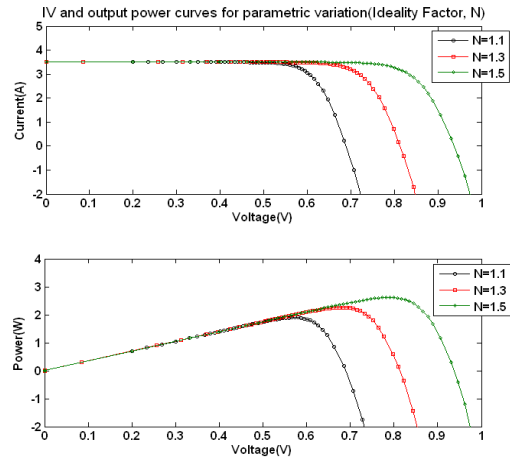


Fig. 5. IV and PV Curves for parametric variation of Ideality Factor, N

Table 3. Ideality Factor, N Variation

Ideality Factor, N	No. of cells	1.1	1.3	1.5
V_m (V)	1	0.5731	0.6836	0.7910
P_m (W)	1	1.9024	2.2630	2.6245
V_m (V)	2	1.1634	1.3821	1.5866
P_m (W)	2	3.8566	4.5784	5.3018

Ideality factor is generally between 1 and 2. It can be observed from simulation results in Fig. 5 and Table 3, that more the value of N was towards 2, more was the power obtained from the solar cell. But the simulation results with $N=1.5$, do not reflect realistic results, as obtaining such high value of V_{oc} is practically not possible with the type of solar cell used since cells with high N value also show high reverse saturation current, I_s , which would normally result in low V_{oc} .

3.1.4. Variation in Temperature

The effect of temperature on the maximum output power, P_m of the cell was investigated. R_s was kept at 0.01 ohm. Irradiance (I_r) value was taken as 476.84 W/m^2 . The Ideality factor, N was taken as 1.1. Diode reverse saturation current, I_s , was taken as 0.1nA at 25°C. The Circuit Temperature (SPICE Environment Parameter) was varied in steps of 20 °C from 25 °C to 85 °C.

Observations from simulations of Temperature variations are shown in Fig.6 and Table4. It can be observed that increase in temperature adversely affected the power obtained from the solar cell and hence P_m . The reason of reduction in power with increase in temperature is due to the increase in I_s with temperature. For single cell, V_m fell by approx 1.75mV/°C, and for two cells, V_m fell by approx 3.5mV/°C.

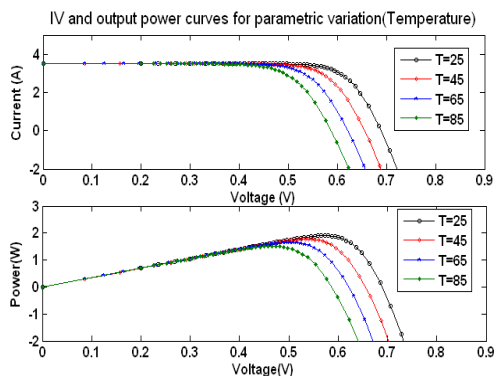


Fig. 6. IV and PV curves for parametric variation of Temperature

Table 4. Temperature Variation

Temperature (°C)	No. of cells	25	45	65	85
V_m (V)	1	0.5731	0.5331	0.5021	0.4655
P_m (W)		1.9024	1.7715	1.6424	1.5137
V_m (V)	2	1.1634	1.0907	1.0200	0.9453
P_m (W)		3.8566	3.5996	3.3434	3.0883

3.1.5. Variation in Irradiance

Changes in I-V and P-V Characteristics are plotted for the variation in Irradiance, I_r , in Fig.7. R_s was taken as 0.01 ohm, Ideality factor, N is taken as 1.1. Diode reverse saturation current, I_s was taken as 0.1nA. The Circuit temperature (SPICE Environment Parameter) was kept at 25°C. Irradiance was varied in steps of 100 W/m² from 300 W/m² to 500 W/m².

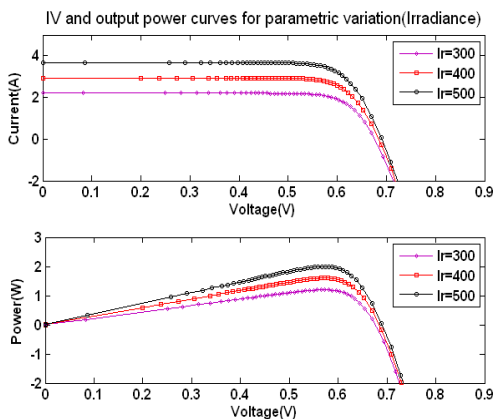


Fig. 7. IV and PV Curves for parametric variation of Irradiance

Table 5. Irradiance Variation

Irradiance (W/m ²)	No. of cells	300	400	500
V_m (V)	1	0.5726	0.5718	0.5736
P_m (W)		1.1954	1.5971	1.9937
V_m (V)	2	1.1552	1.1593	1.1584
P_m (W)		2.4240	3.2381	4.0426

From Fig. 7 and Table 5, it can be observed that the irradiance value impacted the short-circuit current, I_{sc} , as

well as open-circuit voltage, V_{oc} , but more affected was the value of I_{sc} . As irradiance value increased, the short -circuit increased and the maximum power, P_m also increased.

4. Conclusion

Model for simulation of a solar cell has been developed in Simelectronics (MATLAB/Simulink) using solar cell block and other interfacing blocks. In all the simulations, it could be observed that two solar cells in series yield approximately double the power of single solar cell. So, it can be said that for increasing the power to the required value, the modules of solar cells can be created with the combination of solar cells in series. MATLAB with integrated Simelectronicstoolbox, can be used to simulate modules of solar cells under different conditions and can substitute for expensive experiments on actual solar cells.

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