

Designing and Modelling of Solar Photovoltaic Cell and Array

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Abstract: This paper presents the simulation model of PV-cell in MATLAB/Simulink; further performance of PV module/array is analyzed by simulation results. Equivalent circuit of solar cell and mathematical model for solar cell and array are examined in this paper. Further V-I and P-V output characteristic of solar PV-cell are representing a maximum power point (MPP) for further analysis. Output effects by weather condition, irradiance and temperature are analyzed completely in this paper.

Keywords: PV Cell, MPP, Equivalent circuit, modeling.

I. INTRODUCTION

The use of renewable energy resources like solar energy and wind energy is increasing rapidly for electricity generation purpose. Solar energy can be converted into electricity by using photovoltaic cell. A PV cell can convert photon energy into the form of electrical signals, this method of power generation does not harm the ecosystem hence PV power generation systems are becoming popular for generation in small scale as well as in large scale production [1]. PV micro-power plant installation and maintenance is easy and its power can be fed to local substations. Hence small scale power plant business is becoming increasingly popular. This paper is presenting a mathematical model of solar array and accomplishes a simulation model in MATLAB/Simulink. Output V-I and P-V characteristic and performance at different irradiance and temperature are analyzed. Thus, this research work is helpful to understand the behavior of the solar cell and array [2][3].

II. MODELLING OF SOLAR CELL AND ARRAY

Modeling of solar cell can be expressed by many ways in software packages like MATLAB & P-Spice etc. and there are many methods to represent a model as like Mathematical block modeling, Embedded MATLAB Programming and Physical block modeling. Here physical block of solar cells are used for the modeling of PV module. The behavior and characteristic of solar cell can be well understood by the mathematical expression or formulas [3] [4].

MATHEMATICAL MODEL OF SPV CELL

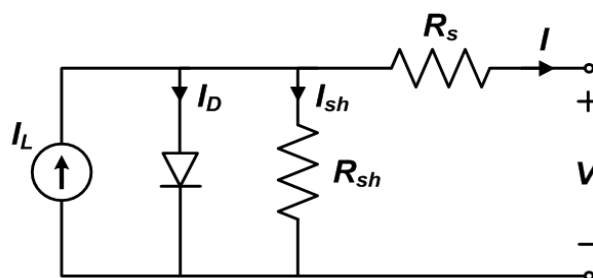


Figure 1: Equivalent circuit solar cell

The practical model of single solar cell is shown in figure 1. In this circuit R_s represents series resistance of PN junction cell and R_{sh} represents shunt resistance which is inversely in relation with leakage current to the ground. Series resistor has great impact on the I-V characteristic of solar cell. I_d and I_{sh} are diode current and shunt leakage current where output terminal current I is evaluated by applying KCL in equivalent circuit of solar cell [3][5]:

$$I = I_{ph} - (I_d + I_{sh})$$

This equation is simplified by taking sum of saturation current and shunt leakage current as I_o and hence simplified equation is [3]:

$$I = I_{ph} - I_o$$

Photon current is generated on absorption of solar radiation by solar cell hence photocurrent value is directly related to variation in solar irradiance and temperature and that is [3]:

$$I_{ph} = (I_{scr} + k_i \Delta T) \frac{G}{G_r}$$

Where in this equation I_{scr} is rated solar current at nominal weather conditions (25°C and 1000w/m²), k_i is short circuit temperature coefficient. G is solar irradiance in W/m² and G_r is nominal irradiance in normal weather conditions (25°C and 1000w/m²). ΔT is difference of operating temperature and nominal temperature ($T - T_{ref}$). On the other hand, solar cell reverse saturation current will be calculated by[7]:

$$I_o = I_{rs} \left(\frac{T}{T_{ref}} \right)^3 \exp \left[\left(\frac{q E_{go}}{A K} \right) \left(\frac{\Delta T}{T_{ref} T} \right) \right]$$

Where I_{rs} is reverse saturation current of cell for nominal temperature and irradiance values and E_{go} is band-gap energy of semiconductor material. The values of I_{ph} and I_o will expand the value of I and it will be as follows [5][6]:

$$I_{pv} = I_{ph} - I_o \left[\exp \left(\frac{q(V_{pv} + I_{pv} R_s)}{A K T} \right) - 1 \right] - \frac{(V_{pv} + I_{pv} R_s)}{R_p}$$

MATHEMATICAL MODEL OF SOLAR MODULE AND ARRAY

Since a typical PV cell produces less than 3.5 W at 0.6V approximately, then high power can achieve by connecting many solar cells in series-parallel configuration. This configuration can be setup by connecting PV module in series and parallel connections and this group of several PV modules assembled in a PV tray is called as Solar array. Configuration of PV arrays depends on required rated voltage and current of a power plant. If N_s cells are connected in series and N_p cells are connected in parallel then equation of I_{pv} can be expressed as[7][8][9]:

$$I_{pv} = N_p I_{ph} - N_p I_o \left[\exp q \left(\frac{V_{pv} + I_{pv} R_s}{N_s A K T} \right) - 1 \right] - \frac{N_p V_{pv} + I_{pv} R_s N_s}{R_p N_s}$$

Efficiency of PV module is highly sensitive to the small changes in series resistance (R_s) and poorly sensitive to the variation in parallel resistance (R_p). Therefore shunt resistance is assumed to be open and we can obtain a revised equation of I_{pv} by putting the value of shunt resistance is infinity ($R_{sh} = \infty$)[9]:

$$I_{pv} = N_p \left[I_{ph} - I_o \left[\exp q \left(\frac{V_{pv} + I_{pv} R_s}{N_s A K T} \right) - 1 \right] \right]$$

We know that series resistance is very small (around 0.005 to 0.01) then for an ideal solar cell there is no series resistance (no series losses) and no leakage to ground (no shunt resistance) therefore R_s and R_{sh} are neglected by putting $R_s = 0$ and $R_{sh} = \infty$. The expression for ideal cell is simplified for I-V characteristic of solar cell and expression of ideal single cell is as follows:

$$I_{pv} = I_{ph} - I_o \left[\exp \left(\frac{q V_{pv}}{N K T} \right) - 1 \right]$$

III. SIMULATION MODEL OF PV SYSTEM

Simulation of PV cell has performed in MATLAB Simulink and MATLAB M-file software system. Parameters of physical solar blocks are defined by short circuit current and open circuit voltage preset values. The parameters and their input values are mentioned in the table given below:

Table 1: Parameter Specification of solar cell:

Parameters	Value
Short circuit current(I_{sc})	7.34 A
Open circuit voltage(V_{oc})	0.6 V
Irradiance (G)	1000 W/m ²
Quality factor (N)	1.5
Series resistance (R_s)	0 Ω

V-I characteristic and PV characteristic of solar cell at nominal temperature and irradiance are evaluated by using simulink model shown in fig 2. Varying resistive load is connected at the output and output power is depends on the parameter value of load. If resistive load is very small then I-V curve is in saturation region(almost equivalent to short circuit current) and when varying resistive load is large then output voltage is at maximum value(almost open circuit voltage). The output waveform of current, voltage and power with respect to time are evaluated by using this simulink model in the figure 2. This represents non-linear behavior of solar cell and results are mentioned later in this paper.

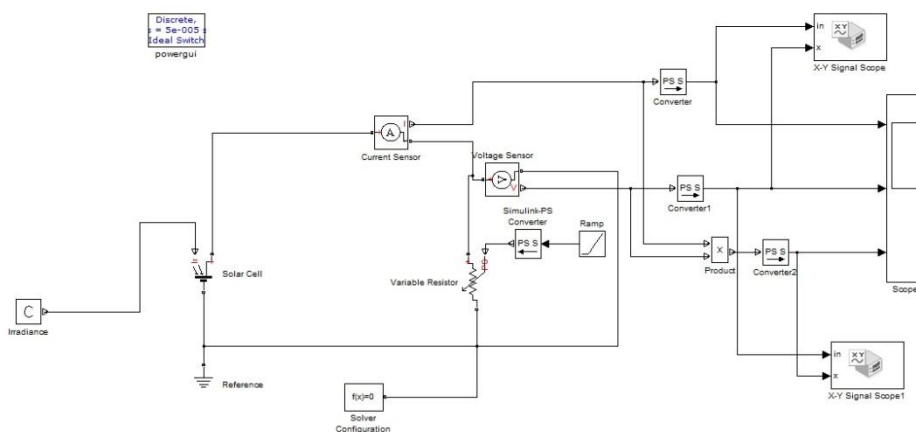


Figure 2: simulink model for characteristic evaluation of solar cell.

SIMULATION MODEL OF PV ARRAY

Modeling task has performed in MATLAB/Simulink library to create a solar array. Series and parallel connections of PV modules are prepared from solar cell blocks taken from simulink- library. Parameter specifications of solar cell are already discussed in table 1. Each module has series connection of 36 PV cells and model contains four such modules. Each of two modules is connected in series by interconnecting positive terminal of one module to the negative terminal of other module. These two strings of solar modules are connected in parallel by interconnection of same terminals (positive terminals are connected together and negative terminals are connected together). Hence there are 72 cells in series and two strings of 72 cells are connected in parallel ($N_s=72$ and $N_p = 2$). Solar array model is shown in figure 3 and specifications of one module and complete array are mentioned in the table 2 and table 3.

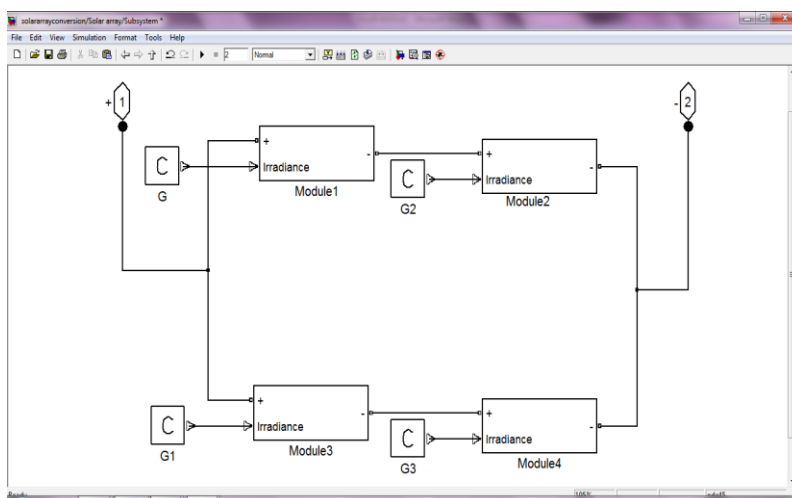


Figure 3: PV array model.

Table2: Electrical Specification of test module.

P_{max}	118.5 W _p
Short circuit current	7.34 A
Open circuit voltage	21.6 V
Voltage at Pmax	18 V
Current at Pmax	6.6 A
Number of cells	36

Table 3: Electrical specification of test array.

Peak power (W_p)	480
Open circuit voltage- V_{oc} (V)	42
Short-circuit current- I_{sc} (A)	14.68
Reference irradiance- G_r (W/m^2)	1000
Reference temperature- T_r (k)	298
Number of cell in Series- N_s	2 module = 72

Number of cell in Parallel- N_p	2 string = 2
Series resistance (Ω)	0.17
Ideality factor-n	1.35
Band-gap Energy- V_g (eV)	1.11-1.12

IV. RESULTS AND DISCUSSION

The behavior of this proposed model has been evaluated by mathematical equation and implemented in matlab environment. The P-V and V-I characteristics are describing character of PV cell. Open circuit voltage, short circuit current and maximum power point defines to remarkable point [10][11] for getting the maximum power point at any input irradiance to solar cell.

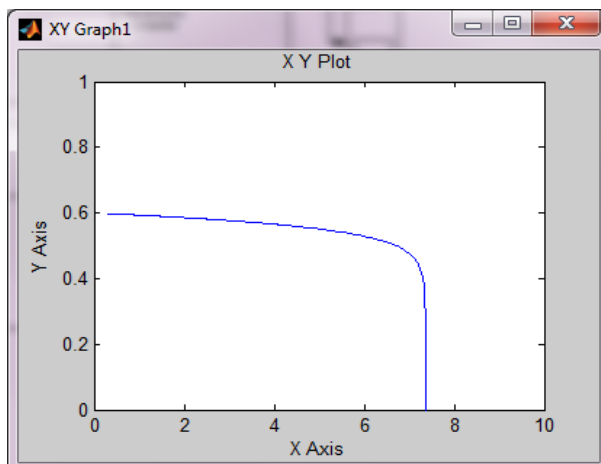


Figure 4 : I-V characteristic of solar cell.

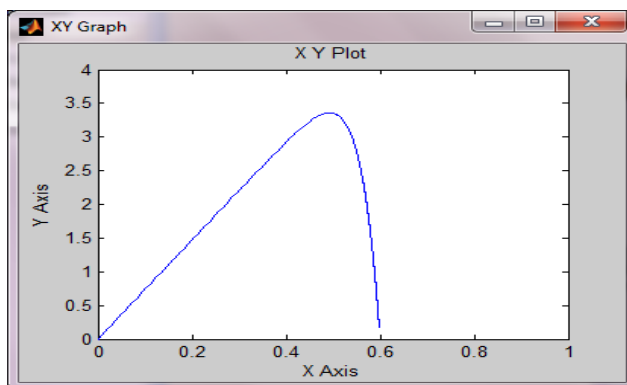


Figure 5: P-V characteristic of solar cell.

The output waveform of current, voltage and power with respect to time for a single solar cell are resulted by using simulink model represented in figure 2. This represents non-linear behavior of solar cell as shown in figure 6. Value of maximum current is 7.36 Ampere is decaying exponentially, maximum value of voltage is 0.6 volt and maximum power output is 3.5 W_p . This signal waveform is received by using a variable type resistive load with ramp input.

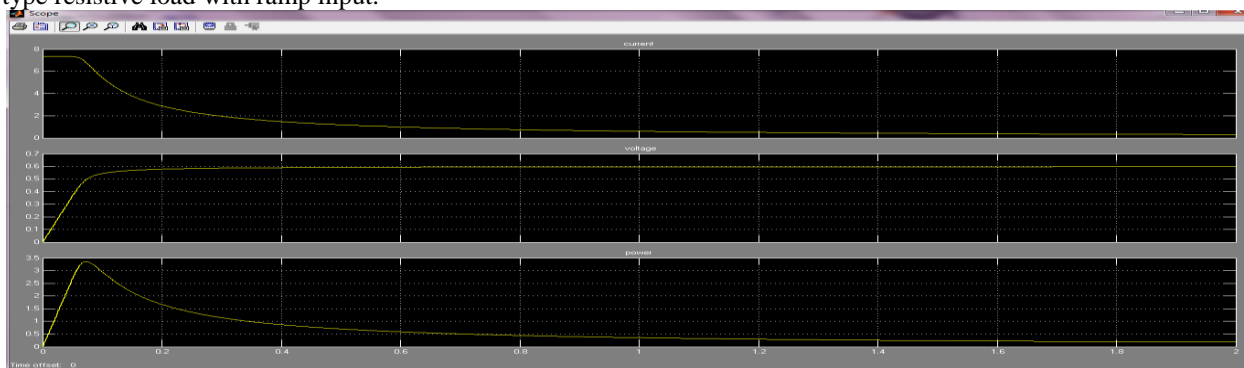


Figure 6: Current, Voltage and Power waveform of solar cell.

Simulation result for array is mentioned below and it verifies to the specifications mentioned above in the table 2 and 3.

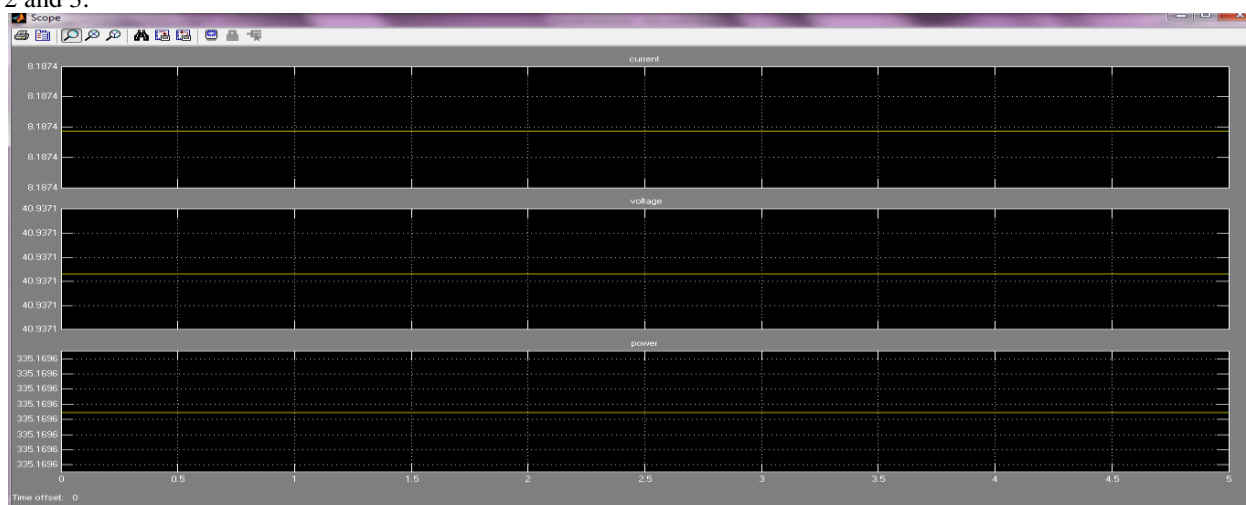


Figure 7: Electrical characteristic of solar array.

Output power is affected by weather parameter variations that are temperature and shading. If solar temperature increases above nominal value then voltage losses is from 0.022 to 0.056 volts per degree. Partial shading on modules is causes of heating up the solar cells. Although thin film modules are not much affected by temperature and shading than mono-crystalline and poly-crystalline solar module. P-V and V-I waveform for different irradiance and temperature are described below [12]:

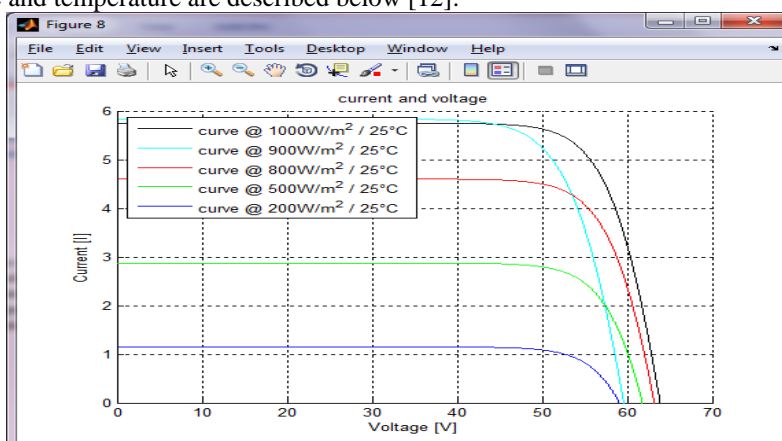


Figure 8: MATLAB Model I-V characteristic for constant temperature and varying irradiance.

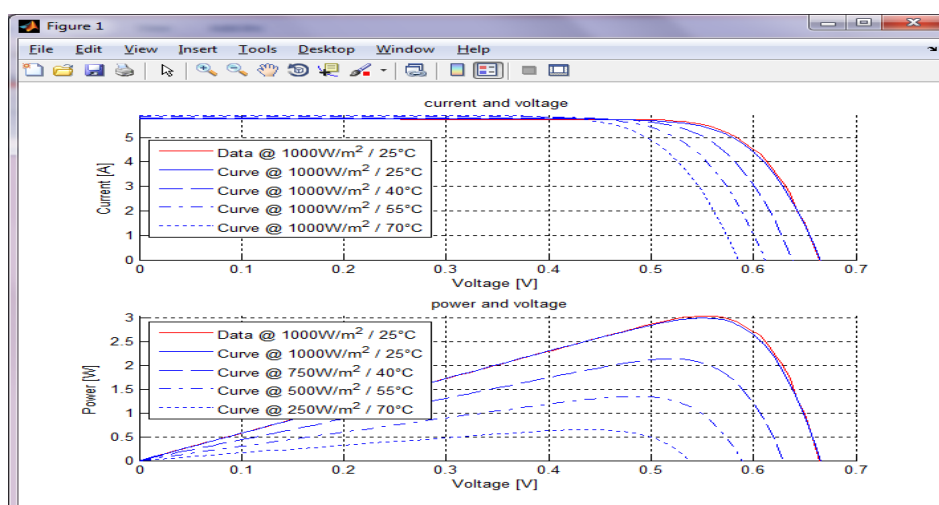


Figure 9: MATLAB Model I-V characteristic for constant irradiance and varying temperature and for varying temperature and irradiance.

V. CONCLUSION

The generalized model of PV cell and module has been presented in MATLAB/Simulink and results are validated within this paper. Results are executing that this test module has achieved the performance level with commercial models. Different irradiance and temperature explains about their affect clearly. Hence this model and research work is expected to characterize and exhibit the behavior of solar cell completely.

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