# Mathematical Modeling of PV Cell

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***Abstract*- Because physical modeling of the PV cell is inefficient to analyze the output data of photovoltaic cells so with the help of mathematical modeling approach, the analysis is done. In this study the mathematical modeling of the photovoltaic cell and the step-by-step simulation procedure of photovoltaic cells in the matlab Simulink is shown. Photovoltaic array made up of photovoltaic modules has non-linear characteristics. This photovoltaics simulation is based on the fundamental mathematical equation of the photovoltaic cell taking all the physical and environmental effects such as cell temperature and irradiation. To determine the characteristics of PV modules in various situations, namely at various levels of irradiance and temperature. The results indicated that the power output, voltage, and current output of a PV module may be determined by varying the irradiation and temperature. In this paper a relation between cell temperature, irradiation and efficiency is proposed and all the effects are analyzed.**

**Keywords-** Modeling Behavior, Matlab/Simulink, Photovoltaic Array, P-V and I-V curves, Sun Irradiation, Temperature

## 1. INTRODUCTION

Energy sources that are inexhaustible and non-polluting are the need of the hour due to the deficit of fossil fuels and the carbon footprint made through the latter's usage. Therefore, renewable energy sources have become an important contributor in the world's energy requirement. Photovoltaic power is a technology that is widely accepted and used, and has experienced very fast growth in the last 10 years [1]. Mathematical modeling of photovoltaci array/module/cell is enhanced for better elaboration of its working to the researchers. The different models are used by researchers for different softwares such as C language programming, Microsoft Excel, Matlab/Simulink or the tool boxes they developed.
A relation has been found out to calculate the output current from the info of voltage, solar radiation and temperature within the matlab environment in the study of [2] and [3]. A limitation of this method is that the reader needs knowledge of programming to follow. Another method for the simulation of PV array is the combination of C-programming and Matlab code which is more difficult to clarify [4]. The model proposed herewith is based on the mathematical equations of photovoltaic array and solar cells, built with blocks in matlab simulink environment in [5]-[8] The effect of environmental elements such as sun irradiation and temperature, as well as physical parameters such as series resistance (Rs), shunt resistance (Rsh), diode quality factor, and saturation current, are investigated in these studies. For the readers, these articles lack a step wise simulation approach.
This difficulty is solved by the papers of [9] and [10]. Solar models developed in the simulink environment are explained in the papers of [11] and [12]. Two aspects solar radiation and temperature are defined in these papers without step-by-step procedure.
In this paper, the step-by-step effect of cell temperature and solar radiation on the photovoltaic cell/array/module is shown with the matlab simulink. Here, the mathematical equations for photovoltaic cells and the relation between them are given. In the last the I-V and P-V characteristics are shown with their explanations.

## 2. MODELING OF SOLAR CELL

A solar cell is basically a p-n junction fabricated in a thin layer of semiconductor. This directly changes the solar energy in DC currents through photovoltaic effect. Solar cells when exposed in the sunlight, photons with higher energy than the band gap energy of the semiconductor creates some electron-hole pairs proportional to the incident irradiation.
The equivalent circuit of PV cell shown in Fig. 1.

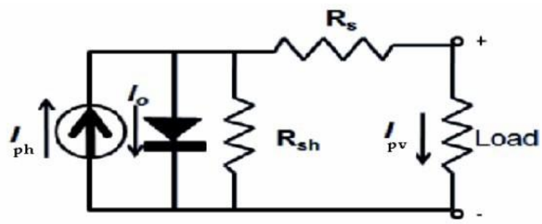



**Fig. 1** PV cell is modeled as diode circuit

The photovoltaic panel is modeled mathematically as given in [13-15].
Module photo-current

$$I_{PH} = [I_{SC} + K_I\,(T_C - T_{Ref})]\,S \qquad (1)$$

Where, $I_{SC}$ is the cell's short circuit current, $K_I$ is the cell's short circuit current coefficient, $T_{Ref}$ is the cell's reference temperature, and S is the solar insolation in kW/m$^2$

Equation for reverse saturation current

$I_{RS} = Isc/[\exp(qV_{OC}/N_S knT) - 1]$ (2)

Where, q ($=1.6\times10^{-19}$C) is an electron charge, k ($=1.38\times^{-23}$J/K) is a Boltzmann's constant, n is diode quality factor and $V_{oc}$ is open current voltage.

Module saturation current

$I_o = I_{RS}(T/T_r)^3 \exp [q\, E_G (1/T_r - 1/T)/kA]$ (3)

Where, $I_{RS}$ is the cell's reverse saturation current, $E_G$ = band gap energy.

Output current of PV module

$I = N_p I_{PH} - N_p I_o [\exp (q (V/ N_S + IR_S)/k\, T_C\, A)-1] -( VN_p/N_s + IR_S)/R_{SH}$ (4)

T = cell's working temperature, A= ideal factor, $R_{SH}$ = shunt resistance, and $R_S$ = series resistance.

## 3. REFERENCE MODEL

A DS 80W reference model is used and their electrical properties are taken from manufractures data

**Table 1:** Electrical Properties

| | |
|---|---|
| Rated Power | 80W |
| Voltage at Maximum Power | 18.09 |
| Current at Maximum Power | 4.43A |
| Open Circuit Voltage | 22.24V |
| Short Circuit Current | 4.76A |
| Number of Cells in Series | 36 |
| Number of cells in Parallel | 1 |

## 4. STEPS FOR MODELING

Step 1: Make a subsystem in Matlab Simulink to find out the photocurrent with the help of photocurrent equation. The circuit within the subsystem is shown in figure 2.

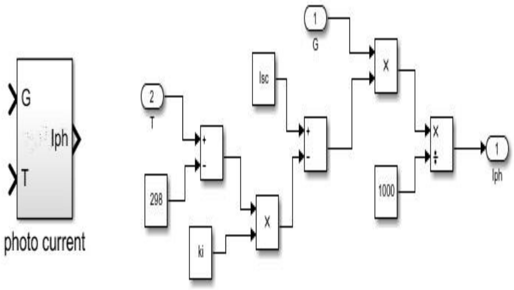



**Fig. 2**. Subsystem with the circuit of photocurrent

Step 2: Make subsystem for Reverse saturation current in matlab Simulink with the help of reverse saturation current equation. The circuit for the subsystem is also shown in the figure 3

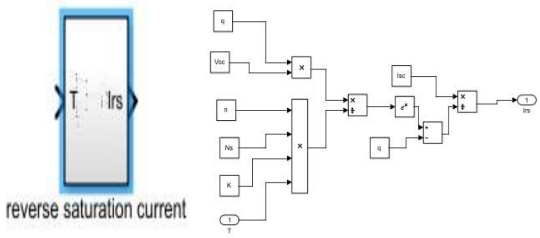



**Fig. 3**. Subsystem with the reverse saturation circuit

Step 3: Make a subsystem in Matlab Simulink to find out the module saturation current with the help of equation 3. The circuit within the subsystem is shown in figure 4.

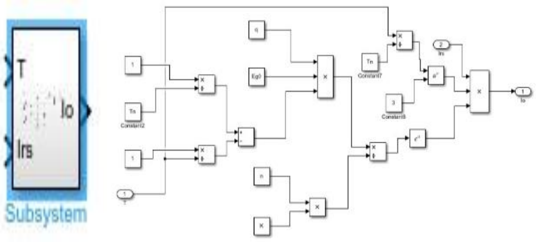



**Fig. 4** Subsystem with the module saturation circuit

Step 4: Make a subsystem in Matlab Simulink to find out the shunt current with the help of shunt current equation. The circuit within the subsystem is shown in figure 5.

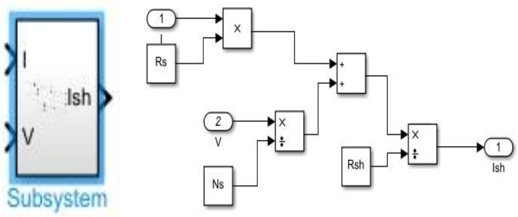



**Fig. 5**. Subsystem with the circuit of shunt current

Step 5: Make a subsystem in Matlab Simulink to find out the shunt current with the help of shunt current equation. The circuit within the subsystem is shown in figure 6.

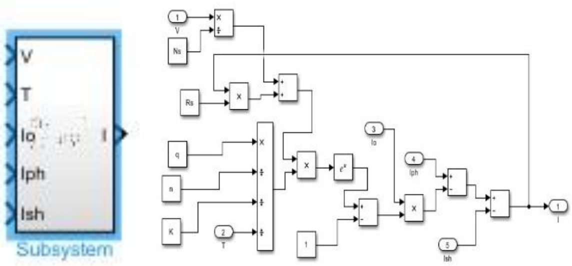



**Fig. 6**. Subsystem with the circuit of module current

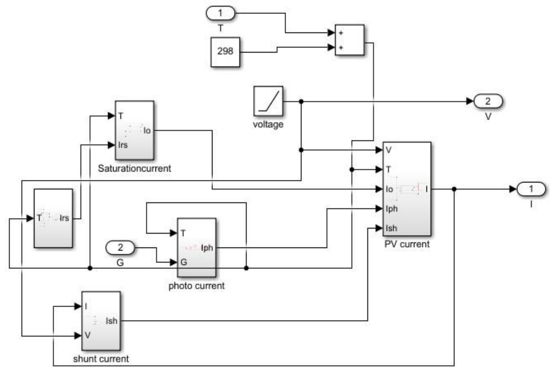



**Fig. 7** PV module and the circuit

Step 6: All thses subsystems are interconnected to make a circuit of PV module and further connected with some inputs. As shown in figure 7.
The final model of the PV system is shown below with the graph plot elements.

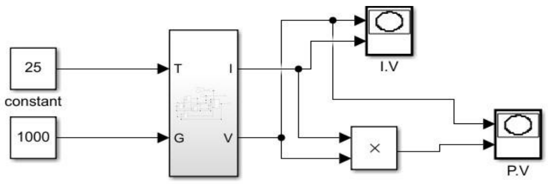



**Fig 8** PV module with graph plot blocks

## 5. RESULT AND DISCUSSION

From the matlab Simulink model, by giving the input values such as solar radiation and temperature,we get I-V and P-V curves

i. Here, I-V and P-V curves at different operating temperature and at constant solar radiation (1000 W/m$^2$) shown below in figure 9(a) and 9(b) respectively.

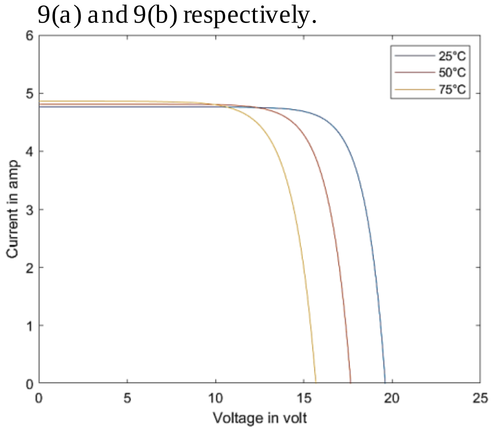



**Fig. 9(a)** I-V curve at different temperature

From the above curves it is clear that if operating temperature of the PV system increases the output voltage decreases more than in comparison of the output current.
Output power directly depends on current and voltage. If voltage decreases with increase in temperature, then output power also decreases.

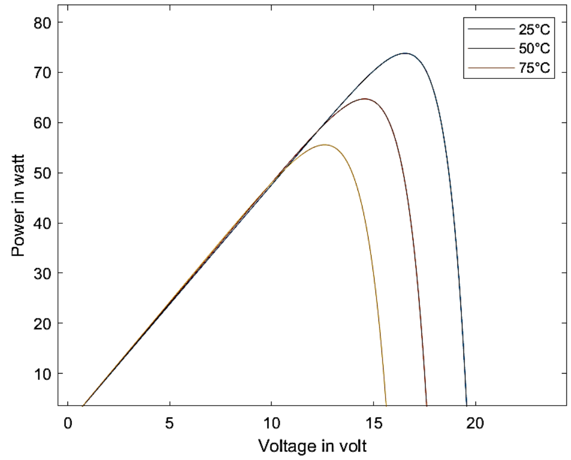



**Fig. 9(b)** P-V curve at different temperature

ii. Here, I-V and P-V curves at different solar radiation and constant temperature drawn below in figure 10(a) and 10(b)

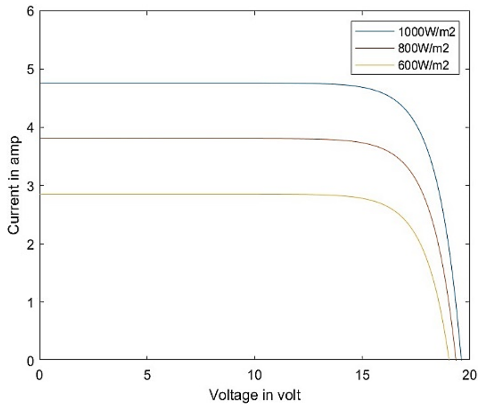
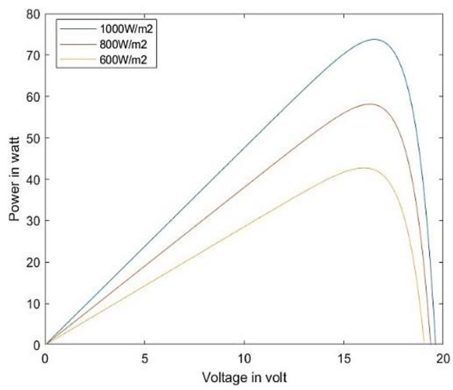



**Fig.10(a)** I-V curve at constant temperature

- From the above curves it shows that if operating temperature is taken as constant and solar radiation value varies then change in output current is more as compare to change in output voltage
- Output power is directly dependent on output voltage and current that is why with decrease in solar radiation decreases the output power.




- **Fig.10(b)** P-V curve at constant temperature

## 6. CONCLUSION
## 7.

The following step-by-step procedure of modeling is shown above, this provides the reader to understand the advantages of PV system. MATLAB Simulink can be assumed as a very frequent and easy tool to predict the behavior of any solar PV cells/modules/arrays under varying environmental conditions such as temperature, irradiation etc. and physical parameters such as series resistance, shunt resistance, ideality factor and so on. Furthermore, This paper proves that with increase the temperature of solar cell power output decreases, same as decrease in solar radiation also decrease the power output of solar cell.

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