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# Mathematical Modeling of Solar Cell Using MATLAB/Simulink

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**ABSTRACT**
This paper presents a Mathematical Model of a photo voltaic cell for single diode cell configurations. In photovoltaic system, solar energy is converted into electricity by photovoltaic effect. The photo voltaic cell model is needed for both hardware and simulators to analyze the characteristics of photo voltaic system. The Mathematical Model was analyzed and simulated using MATLAB/Simulink. On the basis of the output current equation, it is clear that the Photo voltaic output current is related to solar radiation G and temperature T. The proposed theory is verified by simulator for different irradiance and temperature values. The I-V and P-V characteristics of photo voltaic cell from MATLAB/Simulink provide a detailed description of its capacity to convert solar energy and its efficiency.

**Keywords –** Photo voltaic cell, photovoltaic effect, MATLAB/Simulink

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## I. INTRODUCTION

In future Solar Energy is one of the promising options to make more extensive use of renewable sources of energy. The power from the Sun intercepted by the earth is approximately around $1.8 \times 10^{11}$ MW which is equivalent to many thousand times larger than the present consumption rate of all commercial energy sources. The photovoltaic cell will generate electricity from radiations of Sun. A single photovoltaic cell cannot generate sufficient power so in order to generate large power; numbers of individual photovoltaic cells are interconnected together in sealed weatherproof package.

While there are many environmental factors that affect the operational characteristics of PV cells and its power generation, the two major factors are Solar Irradiance G, measured in W/m$^2$ and Temperature T, measured in degree Celsius (°C).From photovoltaic current equation (4), it is clear that photovoltaic current is the function of solar irradiance G and temperature T . The simple PV model can be implemented in MATLAB/Simulink, as it is shown in Figure 2, where the inputs are the solar irradiance G, temperature T and Voltage and the outputs are the photo voltaic current and power. From I-V characteristics we conclude that photovoltaic cell has unique function of both constant voltage and constant current source. Based on the I–V curve shown in figure 4 and figure 6 of a PV cell, the P-V curve shown in figure 3 and figure 5 can be calculated respectively. From P-V characteristics we can find Maximum Power Point.

## II. SOLAR CELL EQUIVALENT CIRCUIT MODEL

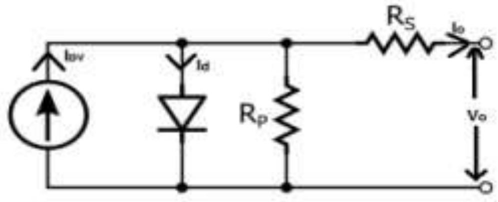


**FIGURE 1:** SOLAR CELL EQUIVALENT CIRCUIT

Figure 1 shows single diode solar cell equivalent circuit model. Generated current from solar panel depends on the intensity of the light hitting the cell D which is p-n semiconductor junction diode. The current source with diode makes up ideal model of PV cell, but in real life there are additional parasitic components. Those components are series resistance and parallel resistance. The value of series resistance is very low as compared to parallel resistance so, the value of parallel resistance is generally neglected in simplified circuit.

## III. MATHEMATICAL EQUATIONS

$$I_{rr} = I_{scr} / (e^{(q \times V_{oc} / K \times N_s \times A \times T_{rk} - 1)}) \quad (1)$$

$$I_d = I_{rr} \times (T_{ak} / T_{rk})^3 \times e^{[(E_g \times q / K \times A) \times (1/T_{rk} - 1/T_{ak})]} \quad (2)$$

$$I_{pv} = [I_{scr} + (K_i \times (T_{ak} - T_{rk}))] \times S/1000 \quad (3)$$

$I_o = N_p \times I_{pv} - N_p \times I_d \times \{e^{[(q/N_s \times A \times K \times T_{ak}) \times (V_o + I_o \times R_s)]} - 1\}$
(4)

$I_o$ is the output current of the PV module.
$V_o$ is the output voltage of the PV module.
$T_{rk}$ is the reference temperature in kelvin.
$T_{ak}$ is the module operating temperature in kelvin.
S is the illumination ($W/cm^2$).
q is charge on electron which is $1.6 \times 10^{-19}$ C.
A=1.3 which is an ideality factor.
K is Boltzmann constant which is $1.3805 \times 10^{-23}$ J/K.
$E_g$ is band gap of silicon which is 1.12 eV.
$I_{scr}$ is the PV module short circuit current at 25 and S=1000 $W/cm^2$.
$N_s$ is number of cells connected in series.
$N_p$ is number of cells connected in parallel.
$K_i$ is short circuit temperature coefficient at $I_{scr}$ with value 0.0013 A/°C.
$R_s$ is the series resistance of PV module.
$I_{pv}$ is current generated by incident light.
$I_d$ is PV module saturation current.

## IV. SOLAR PANEL SPECIFICATION TABLE

**TABLE 1 SPECIFICATION OF THE SOLAR PANEL**

| Parameters | Value |
|---|---|
| $V_{oc}$,open circuit voltage | 21.8 V |
| $I_{sc}$,short circuit current | 3.11 A |
| $V_{mp}$,voltage at MPP | 17.44 V |
| $I_{mp}$,current at MPP | 2.86 A |
| $P_{mp}$,power at MPP | 50 W |
| $N_s$,number of cell in series | 36 |
| $N_p$,number of cells in parallel | 1 |
| $R_s$,series resistance | 0.45 ohm |

All the parameters of cell are provided in Table 1. Open circuit voltage is maximum voltage available from solar cell when current through solar cell is zero and short circuit current is the current through solar cell when voltage across solar cell is zero.

## V. SOLAR CELL SIMULINK MODEL

Based on the output equation number (4) output current is the function of solar irradiance and temperature, which is used to find out PV current for a given voltage.

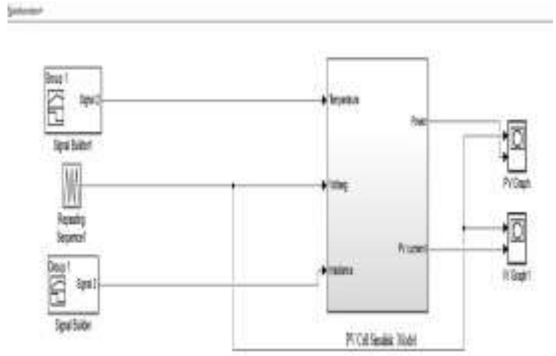

**Figure 2:** Solar Cell Simulink Model

The figure 2 shows mathematical model implemented in MATLAB/Simulink, where the inputs are temperature, Irradiance and voltage and the output is PV current. Signal builder block is used to generate temperature and irradiance and repeating sequence is used to generate voltage. Simulink model shown in figure 2 is used to perform analysis of PV solar cell by controlling two major parameters, irradiance and temperature. In first case temperature is kept constant and irradiance is varied and in second case irradiance is kept constant and temperature is varied to obtain the characteristics.

## VI. SIMULATION RESULTS AND DISCUSSION

**Case 1:**
When irradiance is varying and temperature is kept constant.

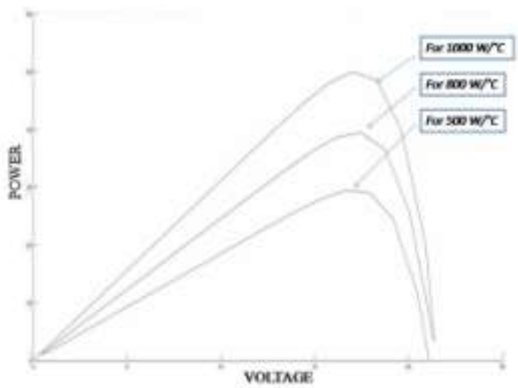


**Figure 3:** P-V characteristics of PV cell at different irradiance values.

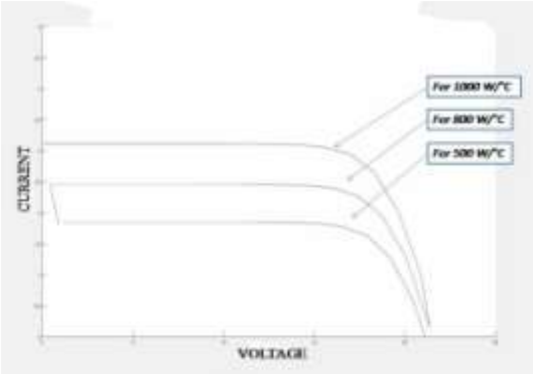


**Figure 4:** I-V characteristics of PV cell at different irradiance values.

Figure 3 and figure 4 shows the P-V characteristics and I-V characteristics of PV cell at different irradiance respectively.

**Case 2:**
When temperature is varying and irradiance is constant.

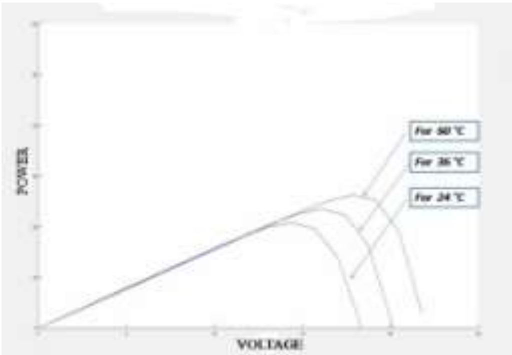


**Figure 5:** P-V characteristics of PV cell at different temperature values.

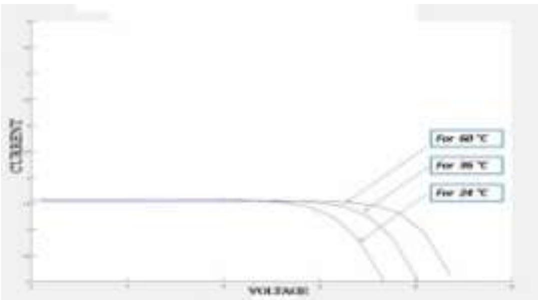


**Figure 6:** I-V characteristics of PV cell at different temperature values.

Figure 5 and figure 6 shows the P-V characteristics and I-V characteristics of PV cell at different temperature respectively.

## VII. CONCLUSION

Simulink model of photovoltaic cell is successfully implemented in this paper. PV module is simulated in MATLAB/Simulink tested at varying irradiance and temperature. Figure 3 and figure 4 show that current varies linearly with respect to irradiance and voltage also increases but not significantly. Figure 5 and figure 6 shows that voltage varies linearly with respect to temperature and current decreases but not significantly. Hence from the results we can easily observe that photon current is the function of irradiance and temperature.

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