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# A Proposed Model of Photovoltaic Module in Matlab/Simulink<sup>TM</sup> for Distance Education

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## Abstract

This paper define a circuit-based simulation model for a PV cell in order to allow estimate the electrical behavior of the cell with respect changes on environmental parameter of temperature and irradiance. An accurate PV module electrical model is presented based on the mathematical equations. The general model was implemented on MATLAB/Simulink environment, and accepts irradiance as variable parameters and outputs the I-V characteristic. A particular typical solar panel was used for model evaluation, and results was compare with points taken directly from the manufacturer's published curves and show excellent correspondence to the model. With this proposed module different types of PV modules could be developed and students could be investigate and learn the P-V or V-I characteristics easily. Furthermore, a by-pass diode is added to the PV cell design with this addition, in different insulation combinations will be able to investigate likewise partial shade.

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## 1. INTRODUCTION

Recent developments in computer hard-ware and software now make it possible to provide students with interactive programs that can be considered as midway between regular labs and lecturers and that allow us to display multiple-view representations of given dynamic system, and some of its attributes, on the computer screen (Rosal, 2005) Virtual laboratories are recognized as an attractive complement to traditional engineering laboratories. Among other advantages, they do not require expensive and dedicated equipment, reduces the required time for instruction, and promote student involvement and learning (Muñoz & Díaz, 2010) MathWorks

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tools for technical computing and simulations widely used across various engineering and science disciplines. MATLAB Programming language and interactive environment well suited for computing, algorithms, data processing and visualization. Moreover, Simulink Environment is a practical tool for graphical and model-based simulation of dynamic systems (Eker & Cervin, 1999) (Nchez, Esquembre, Marti, Dormido, & Canto, 2005)(Swamy, Kuljaca, & Lewis, 2002)(Valera, Diez, Vallés, & Albertos, 2005).

The sun's heat and light provide an abundant source of energy that can be harnessed in many ways. Photovoltaic power systems convert sunlight into electricity directly. Research and development efforts are under way to improve efficiency and reduce cost of photovoltaic power systems in applications ranging from roof-top residential to large industrial or electric utility sites (Petreuş, Fărcaş, & Ciocan, 2008). Photovoltaic systems have become globally accepted as a practical and feasible tool for power generation. Researchers' efforts for facilitating PV systems utilization and their integration to currently available systems have been always inspired by the national goal of having renewable and clean energy sources. These efforts successfully solved many of the problems that are attached to PV systems (Mohamed, 2012) Therefore, for a student it is important to learn the characteristics and details about the PV systems before graduation. However, for colleges it is expensive to build a real PV system laboratory.

This paper define a circuit-based simulation model for a PV cell in order to allow estimate the electrical behavior of the cell with respect changes on environmental parameter of temperature and irradiance. An accurate PV module electrical model is presented based on the mathematical equations. The general model was implemented on MATLAB/Simulink environment, and accepts irradiance as variable parameters and outputs the I-V characteristic. A particular typical solar panel was used for model evaluation, and results was compare with points taken directly from the manufacturer's published curves and show excellent correspondence to the model. With this proposed module different types of PV modules could be developed and students could be investigate and learn the P-V or V-I characteristics easily. Furthermore, a by-pass diode is added to the PV cell design with this addition, in different insulation combinations will be able to investigate likewise partial shade.

## 2. MATHEMATICAL MODEL OF THE PV CELL

### Nomenclature

I & V	Cell output current and voltage
$I_{ph}$	Photon or light generated current
$I_o$	PV junction saturation current
$R_s$	Series Resistance
$R_{sH}$	Shunt Resistance
T	Operating temperature
$I_{SC}$	Short circuit current at 25° C and under 1sun
G	Solar Insulation in W/m <sup>2</sup>
$G_{ref}$	1000 W/m <sup>2</sup>
$K_I$	Short ckt. Current temperature coefficient at $I_{SCR}$

$T_{ref}$	Nominal Temperature
$N_p$	Number of parallel connected cells
$N_s$	Number of series connected cells

The simplest model of a PV cell consists of a current source in parallel connection with a diode as shown in figure 1. Photo current  $I_{ph}$  is directly proportional to solar radiation  $G$ . Temperature  $T$  and photo current  $I_{ph}$  have a linear relationship according to equation (1), where  $I_{ph(ref)}$  is photo current which corresponds to reference temperature  $T_{ref}$ . Equation (2) gives photo current at reference temperature. is a constant given by (3). In equation (2) and (3)  $I_{ref}$  is the nominal radiation given by PV’s constructor and  $I_{SC}$  is the short circuit current. All symbols are presented on figure 1 and used in equations refer to a single PV cell (Nema, Nema, & Agnihotri, 2009).

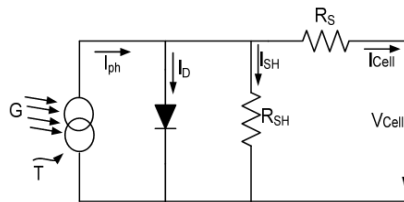


Fig 1. PV Cell equivalent circuit

The Mathematical Equations for PV Cell

$$I_{ph} = I_{ph(T_{ref})} \cdot (1 + K_0 \cdot (T - T_{ref})) \tag{1}$$

$$I_{ph(T_{ref})} = \frac{G}{G_{ref}} \cdot I_{SC(T_{ref})} \tag{2}$$

$$K_0 = \frac{I_{SC(T)} - I_{SC(T_{ref})}}{T - T_{ref}} \tag{3}$$

Diode’s current is given by (4), where  $V_{Cell}$  and  $I_{Cell}$  are output voltage and current for a single PV cell respectively,  $I_o$  is diode’s saturation current,  $V_T$  thermal voltage of it and  $R_S$  is in series resistance.

$$I_D = I_o \cdot \left[ \exp\left(\frac{V_{Cell} + I_{Cell} \cdot R_S}{V_T}\right) - 1 \right] \tag{4}$$

Current  $I_{SH}$  through shunt resistance  $R_{SH}$  according to Ohm’s law is equal to:

$$I_{SH} = \frac{V_{Cell} + I_{Cell} \cdot R_S}{R_{SH}} \quad (5)$$

Taking into account equations (1) – (5) and applying Kirchhoff's current law, I – V characteristic equation (6) is resulted for PV cell:

$$I_{Cell} = I_{ph} - I_o \cdot \left[ \exp\left(\frac{V_{Cell} + I_{Cell} \cdot R_S}{V_T}\right) - 1 \right] - \frac{V_{Cell} + I_{Cell} \cdot R_S}{R_{SH}} \quad (6)$$

Substituting in (6) equations (7) and (8) which gives output voltage V and current I respectively for  $N_s$  in series and  $N_p$  in parallel PV cells and ignoring current through shunt resistance, equation (9) gives the general I – V characteristic for PVs. Equation (10) gives the output power of a PV module consisted of ( $N_s \times N_p$ ) cells.

$$V = N_s \cdot V_{Cell} \quad (7)$$

$$I = N_p \cdot I_{Cell} \quad (8)$$

$$I = N_p - I_{ph} - N_p \cdot I_o \left[ \exp\left(\frac{V + I \left(\frac{N_s}{P}\right) \cdot R_S}{N_s \cdot V_T}\right) - 1 \right] \quad (9)$$

$$P = (N_s \cdot N_p) \cdot V_{Cell} \cdot I_{Cell} \quad (10)$$

Equation (10) is able to be extended for a single PV array which consists of a number of PV modules and for a PV farm with many arrays.

### 3. Modeling The PV Cell and Different Input PV Modules

#### A. PV Cell and PV Module Model

Due to the formulations in section 2 the interface model of PV Modules has been developed in MATLAB/Simulink environment. A parameter login screen is designed for different type PV modules which is shown in Fig. 2 (b). To prevent the hot spot and short circuit problems a by-pass diode is added as shown in Fig. 2 (b). In addition to the PV cell model also PV module is designed. A practical method is used while developing the PV module with a gain ( $N_s$ ) block which can be seen in the right part of the Fig. 2 (a).

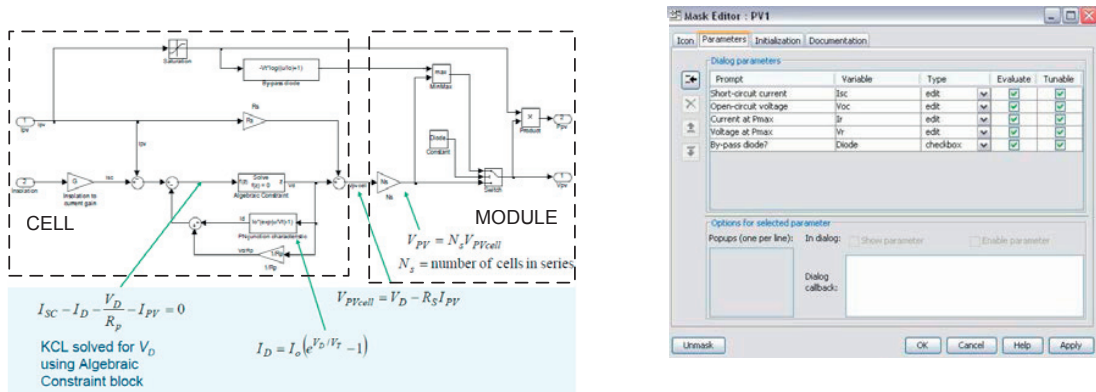


Fig 2. (a) PV Cell and PV Module design in MATLAB/Simulink (b) PV Module parameter login screen

#### B. A Current-Input and Voltage-Input PV Module

In Maximum power point trackers researcher has to be develop an algorithm and this algorithm could be different outputs like maximum current or maximum voltage, therefore designer or student could need different input PV modules for simulations. For this purpose, two types of PV Modules are designed for the user. With the current input and voltage-input PV modules provides a flexible environment to the user.

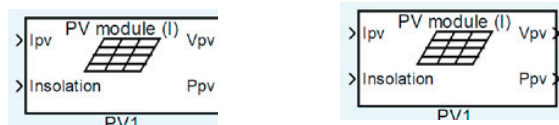


Fig 3. (a) Current-input PV Module

(b) A Voltage-input PV Module

#### 4. Determination of V-I and P-V Characteristics

Student can easily determine the PV characteristic with proposed PV modules with connecting them in series. For a realistic PV system simulation, it is better to connect series the PV modules. Fig. 4 shows the simulation between six series connected PV modules. In this fashion, the output power of the PV system is about 510 W. The output P-V and I-V characteristics in Fig. 5 are obtained from that simulation.

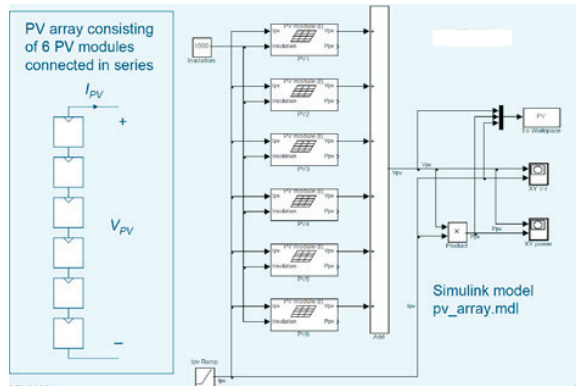


Fig. 4. 6 array connected in series for a PV system simulation and determined the characteristic curves

P-V and I-V characteristics are key points for understanding the PV systems. The need for the Maximum Power Point Tracker (MPPT) is acquired from these characteristics. It can be clearly seen from Fig. 5(a) that there are only one maximum power point in each power curve and the purpose of the MPPT's are operate the PV systems at these maximum power points in different insolation levels. In Fig. 5. (a) different power curves are occurs due to different insolation conditions. When the insolation level is raised the output power is raised continually until the insolation is reached its maximum level.

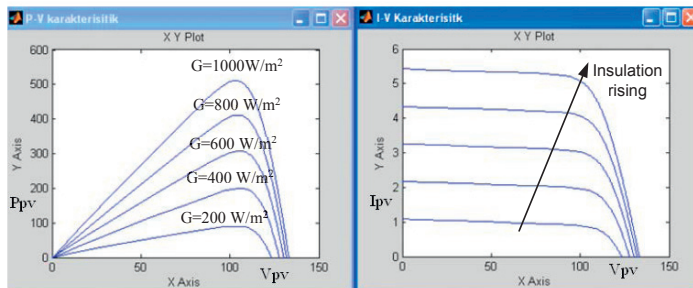


Fig. 5. (a) P-V characteristic

(b) I-V characteristics

#### 5. Reliability test of the model

The reliability of the system is tested with using real PV module parameters and the simulation results are compared with the data sheet values. The real data which is obtained from data sheet is login as shown in Fig. 6

(a) and the real parameters from data sheet are shown in Fig. 6 (b). Although, in the PV modules data sheets has plenty of parameters, with proposed model a few of them enough to develop a realistic PV module. To the login screen the short circuit current, open voltage, voltage and current values at the maximum power point values are entered as shown in Fig. 6 (a) and the real values from data sheet is given in Fig 6 (b).

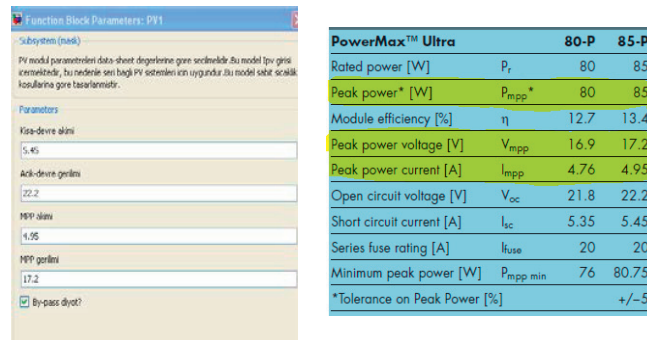


Fig. 6 (a) Parameter login screen with real data sheet values

(b) data sheet parameters

The maximum power for one module is 85 W and 6 module is connected in series which makes the total output power 510 W and voltage value is equal to 103.2 V. The comparison tables of the real data and the simulation results are given in Table 1 and 2 respectively.

Table 1. The real data results

Table 2. The Simulation results

Insulation	MPP Power (W)	MPP Voltage(V)	MPP current (A)	Insulation	MPP Power (W)	MPP Voltage (V)	MPP current (A)
1000 W/m <sup>2</sup>	510 (85*6)	103.2 (17.2*6)	4.95	1000 W/m <sup>2</sup>	510.8243	103.4057	4.9400

### 6. Partial Shade Condition Simulations

If a PV array is partially shaded by a building, a tree, and/or clouds as shown in Fig 7 (a), it becomes insufficient for conventional MPPT schemes to extract maximum power. If modules with different optimal currents, caused by uneven insolation, are connected in series-parallel, MPPs often appear in the power versus voltage characteristic.

In our interface model it is also possible to make a shade condition simulation. In Fig. 7 (b) the sixth panel is exposed to a shade condition. The student only changes the insulation rate to see the effect of the partial shade condition to the PV system.

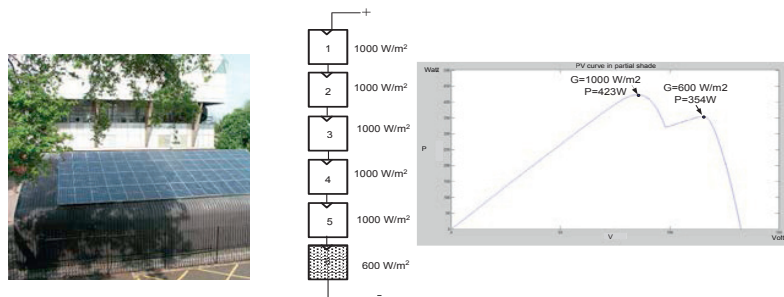


Fig 7. (a) Partial shade occurs because of a tree

(b) partial shade simulation results

## 7. Conclusion

An accurate PV module electrical model is presented and demonstrated in MATLAB/Simulink for a typical 60W solar panel. Given solar insolation and temperature, the model calculates the current for a given voltage. The results from the MATLAB™ model show excellent correspondence to manufacturer's published curves. Finally the model development was used to show the effect of: insolation, temperature, ideality factor and series resistances. This paper is the first step to develop a complete solar photovoltaic power electronic conversion system in simulation. The final objective is develops a general model to simulate the electrical behavior of the PV systems in a grid connected application. With this study students will be able to simulate the PV system without a laboratory.

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