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# A comprehensive MATLAB Simulink PV system simulator with partial shading capability based on two-diode model

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**Abstract**

This paper proposes a comprehensive MATLAB Simulink simulator for photovoltaic (PV) system. The simulator utilizes a new two-diode model to represent the PV cell. This model is known to have better accuracy at low irradiance level that allows for a more accurate prediction of PV system performance during partial shading condition. To reduce computational time, only four parameters are extracted for the model. The values of $R_p$ and $R_s$ are computed by an efficient iteration method. Furthermore, all the inputs to the simulators are information available on standard PV module datasheet. The simulator supports a large array combination that can be interfaced to MPPT algorithms and power electronic converters. The accurateness of the simulator is verified by applying the model to five PV modules of different types (multi-crystalline, mono-crystalline, and thin-film) from various manufacturers. It is envisaged that the proposed work can be very useful for PV professionals who require simple, fast, and accurate PV simulator to design their systems. The developed simulator is freely available for download.


*Keywords:* PV module; Partial shading; Bypass diode; Blocking diode; Simulator; MATLAB Simulink

## 1. Introduction

Large and small scale PV power systems have been commercialized due to its potential long term benefits. Their growth rates have been accelerated by the generous fed-in tariff schemes and other initiatives provided by various governments to promote sustainable green energy. In large PV power generation, systems are dominated by grid-connected; examples can be seen in (Albuquerque et al., 2010; Beser et al., 2010; Chen et al., 2010; Mellit and Pavan, 2010; Yoon et al., 2011). To ensure optimal use of the available solar energy, maximum power point tracking (MPPT) scheme is applied to the power converters (Chaouachi et al., 2010; Enrique et al., 2010; Messai et al., 2011). However, for a proper design of MPPT controller, an accurate simulation model of the module is required. This is especially the case when the peak power point changes continuously due to environmental variations. In particular, one important situation to be considered is the substantial drop of power yield during partial shading condition.

The most important component that affects the accuracy of simulation is the PV cell modeling. For improved accuracy, the two-diode model (with $R_p$ and $R_s$) has been proposed by several researchers (Hovinen, 1994; Gow and Manning, 1999; Hyvarinen and Karila, 2003; Nishioka et al., 2003, 2007; Kurobe and Matsunami, 2005; Chowdhury et al., 2007). Although more to that of single diode model, the inclusion of an additional diode increases the number of computed parameters. Several

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computational methods are proposed (Hovinen, 1994; Gow and Manning, 1999; Chowdhury et al., 2007), but in all of these techniques, new coefficients are introduced into the equations, increasing the computing burdens. An alternative approach to describe the two-diode model is by investigating its physical characteristics such as the electron diffusion coefficient, minority carrier's lifetime, intrinsic carrier density, and other semiconductor parameters (Hyvarinen and Karila, 2003; Nishioka et al., 2003, 2007; Kurobe and Matsunami, 2005). While these models are useful to understand the behavior of the cell, information about these parameters is not always available in commercial PV datasheets.

A comprehensive PV system simulator should fulfill the following criteria: (1) it should be fast, yet can accurately predict the $I$–$V$ and $P$–$V$ characteristic curves, including partial shading condition. (2) It should be a flexible tool to develop and validate the PV system design, inclusive of the power converter and MPPT control. Although existing software packages like P-Spice, PV-DesignPro, SolarPro, PVcad, and PVsyst are available in the market, they are relatively expensive, unnecessarily complex and rarely support the interfacing of the PV arrays with power converters (Ishaque et al., 2011b).

Over the years, several researchers have studied the characteristics of PV modules under partial shading conditions. In (Alonso-García et al., 2006), an experimental study was carried out but was limited to module-level shading. The effect of shading on the output of the PV modules and the changes in their $I$–$V$ characteristics was investigated by (Kawamura et al., 2003). A numerical algorithm was proposed by (Quaschning and Hanitsch, 1996) to simulate the complex shading characteristics of the arrays whereby every element (each cell of the module, bypass diode, blocking diode, etc.) was represented by a mathematical expression. The results were attractive but the simulation was considerably complex, thus limiting its ability to predict the performance of larger systems. A MATLAB based modeling to study the effects of partial shading based on the single diode model was proposed in (Patel and Agarwal, 2008). Although the model is relatively simple, it exhibits serious deficiencies when subjected to high temperature variations. Moreover, it does not account for the open circuit voltage coefficient, $K_V$ (Ishaque et al., 2011a).

Considering the importance of this issue, this paper proposes a fast, accurate, and comprehensive PV system simulator using the MATLAB Simulink environment. The availability of the simulator in the MATLAB platform is seen as an advantage from the perspective of researchers and practitioners alike as this software has almost become a *de-facto* standard in various engineering discipline. An important contribution of this work is the application of the two-diode model that is known to have better accuracy, especially at low irradiance level. It allows for a more accurate prediction of PV system performance during partial shading conditions. To reduce computational time, the model parameters extraction is reduced to four while the values of $R_p$ and $R_s$ are estimated by an efficient iteration method. The accurateness of the model is compared with two other modeling methods namely the $R_s$- and $R_p$-model. In addition, the proposed work supports large array simulation that can be interfaced with MPPT algorithms and actual power electronic converters. This allows for the designer to evaluate the overall system performance when interacting with other components within the systems. It is envisaged that the proposed work can be very useful for PV professionals who require fast and accurate PV simulator to design their system.

## 2. PV module modeling

### 2.1. Modeling using the two-diode model

The two diode model is depicted in Fig. 1. The output current of the module can be described as (Chih-Tang et al., 1957)

$$I = I_{PV} - I_{o1}\left[\exp\left(\frac{V + IR_S}{a_1 V_{T1}}\right) - 1\right] - I_{o2}\left[\exp\left(\frac{V + IR_s}{a_2 V_{T2}}\right) - 1\right] - \left(\frac{V + IR_s}{R_p}\right) \quad (1)$$

where $I_{PV}$ is the current generated by the incidence of light. $I_{o1}$ and $I_{o2}$ are the reverse saturation currents of diode 1 and diode 2, respectively. The $I_{o2}$ term is introduced to compensate for the recombination loss in the depletion region as described in (Chih-Tang et al., 1957). Other variables are defined as follows: $V_{T\ 1,2}$ $(= N_s\ kT/q)$ is the thermal voltage of the PV module having $N_s$ cells connected in series, $q$ is the electron charge $(1.60217646 \times 10^{-19}\ \mathrm{C})$, $k$ is the Boltzmann constant $(1.3806503 \times 10^{-23}\ \mathrm{J/K})$, and $T$ is the temperature of the $p$–$n$ junction in K. Variables $a_1$ and $a_2$ represent the diode ideality constants; $a_1$ and $a_2$ represent the diffusion and recombination current component, respectively. Typically, three points at Standard Test Conditions (STC) $(I_{sc}, 0)$, $(V_{mp}, I_{mp})$ and $(V_{oc}, 0)$ are provided by the manufacturer's datasheet. An accurate estimation of these points for other conditions is the main goal of every modeling technique.

Although greater accuracy can be achieved using this model (compared to the single diode model), it requires the computation of seven parameters, namely $I_{PV}$, $I_{o1}$, $I_{o2}$, $R_p$, $R_s$, $a_1$, and $a_2$. To simplify, several researchers assumed $a_1 = 1$ and $a_2 = 2$. The values are chosen based on the approximations of the Schokley–Read–Hall

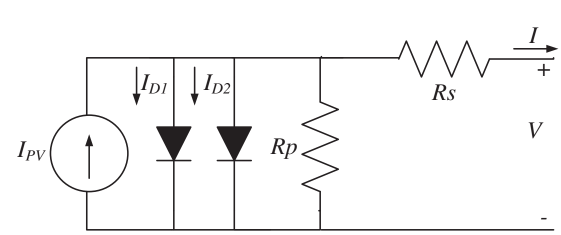


Fig. 1. Two diode model of PV cell.