

STUDY REGARDING MODELING PHOTOVOLTAIC ARRAYS USING TEST DATA IN MATLAB/SIMULINK

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The paper presents a study on two ways of modeling photovoltaic (PV) solar array in Matlab/Simulink environment. The simulation results indicate that, using the proposed model for the source of a PV solar array, the PV output power is higher and have slight variations that imply the choice of PV solar array model as being as close as possible to reality. This paper is useful in modeling PV energy production systems.

Keywords: photovoltaic arrays; mathematical model; simulation; software packages

1. Introduction

Photovoltaic (PV) technology has become a major actor in the electricity sector globally [1] and is currently one of the most developed renewable energy resources being scalable from residential to commercial applications [2]. According to [3] in 2012, the total power of PV systems installed globally is more than 100 GW. Challenges related to development and enforcement of PV systems requires simulation tools able to modeling and analyzing the performance and the behavior of photovoltaic panels [2]. Through modeling and simulation of PV systems is determined the best compromise in design phases. Finding the balance between efficiency and cost of PV components is an extremely important aspect for widespread adoption of this technology [4]. To improved design an integrated control system and accurately predict its performance, designers must understand the behavior of the whole PV system in that is integrated the control system. Matlab and Simulink is a base environment for Model-Based Design to create accurate mathematical models of physical system behavior [4]. PV simulators are

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used for components evaluation of PV system in order to avoid the expensive and time-consuming field-testing process [5].

The current-voltage behavior of the solar cells and PV arrays can be described by several different complex mathematical relationships [6]. In Fig. 1 is given the five parameters (single-diode) solar cell model [2, 7, 9] that is the most used PV cell model which provides a good compromise between accuracy and simplicity [8]. This model is composed from a series resistance R_s (models bulk and contact resistances) connected in series with a parallel combination of a current source, an exponential diodes and a parallel resistance R_p (models leakage currents, primarily due to defects) [2].

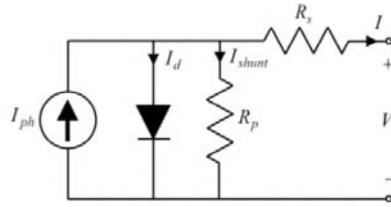


Fig. 1. Five parameters equivalent circuit of solar cell

The output current I of solar cell [2, 7, 9] is:

$$I = I_{ph} - I_s \cdot \left(e^{\frac{V+I \cdot R_s}{N \cdot V_t}} - 1 \right) - \frac{V + I \cdot R_s}{R_p}, \quad (1)$$

where: $I_{ph} = I_{ph0} I_r/I_{r0}$ is the solar-induced current, I_r is the irradiance (light intensity) that falling on the cell in W/m^2 , I_{ph0} is the measured solar-generated current for the irradiance (light intensity) I_{r0} ; I_s is the saturation currents of the diode; N is the quality factor (emission coefficient) of the diode; $V_t = k T/q$ is the thermal voltage, (k is the Boltzmann constant, T is device temperature, q is the elementary charge on an electron); R_s and R_p are the series and parallel (shunt) resistance; V is the voltage at the terminals of PV solar cell.

In [10] is presented a study on modeling PV arrays function of temperature in Matlab/Simulink using experimental data using Curve Fitting Toolbox for creating experimental irradiation–voltage–current (G–V–I) surface. In Curve Fitting Tool is implementing a custom equation of mathematical model with 5 parameters because it is known the shape of these curves and the equation of solar generated current of PV solar array [2]:

$$f(x,y) = a \cdot y - b \cdot \exp((m \cdot x) - 1) - (x + c) / d. \quad (2)$$

This model can be easily used as a source of a PV simulator. It was established that for a given temperature range ($\leq -16^{\circ}\text{C}$), it is necessary to use

another custom equations or another algorithm (e.g. cubic interpolation) to create the model of PV solar array [10].

The objective of this paper consists to compare different ways of modeling PV solar arrays in Matlab/Simulink environment that are the five parameter model of PV array using experimental test data [2, 6] and the five parameter model of PV array using fundamental approaches of first principles Simulink [2]. In this study it is not follow the three-dimensional surface of current–voltage (I–V) characteristic curves of PV solar array but the power obtained at the output of a PV system formed by a PV solar array that is implemented as in [6] and respectively using first principles Simulink [2], a step-down (buck) dc-dc converter, and a MPPT controller with incremental conductance algorithm [2, 11].

The paper has basically four sections. The first section presents the general stage about PV technology, a brief description of modeling single-diode solar cell and the objective of the paper. In the second section are described how the PV solar array are modeled using experimental test data through Curve Fitting Toolbox™ from Matlab®/Simulink® and the PV simulator. The third section presents the results and discussions regarding simulation of PV system. Finally, in the last section of paper are presented the main conclusions of this study.

2. Model description of photovoltaic solar array simulator

Model description of generate a surface fit for the PV array test data

The experimental test data of PV solar array in the form of typical I–V curves are used to generate a mathematical model for a PV panel or array by import test data from Excel® files or another file format and optimization and surface fitting with a Matlab using the Curve Fitting Toolbox. The surface fit is then used to generate the current array and the voltage and irradiation vector needs to parameterize a 2D Lookup Table block in Simulink. To create a source for a PV solar panel must comprised the following stages [2, 10]:

1. Set up figure color map, legend array, figure plotting axis, titles and labels;
2. Load data for 5 levels or more of irradiance: 400 W/m^2 , 600 W/m^2 , 800 W/m^2 , 1000 W/m^2 and 1200 W/m^2 ;
3. Use the Curve Fitting tool to create a fit for this data;
4. Use the auto-generated Matlab function file to create the surface;
5. Create the irradiance and voltage vectors;
6. Use the surface fit object to create the current array: replace NaNs by zeros in the current array and transpose the current array.
7. Save data;
8. Use the array data to parameterize a Simulink 2D Lookup Table block: load the Simulink library, create and open a new Simulink model, add block to model and parameterize.

General description of PV system

The model shown in Fig. 2 represents a variant subsystem of PV solar array that allow choosing between two five parameter PV solar array sources: using experimental test data and using fundamental approaches of first principles Simulink [2], that are connected to a resistive load through a dc-dc step-down converter with MPPT controller implemented with incremental conductance algorithm as in [11].

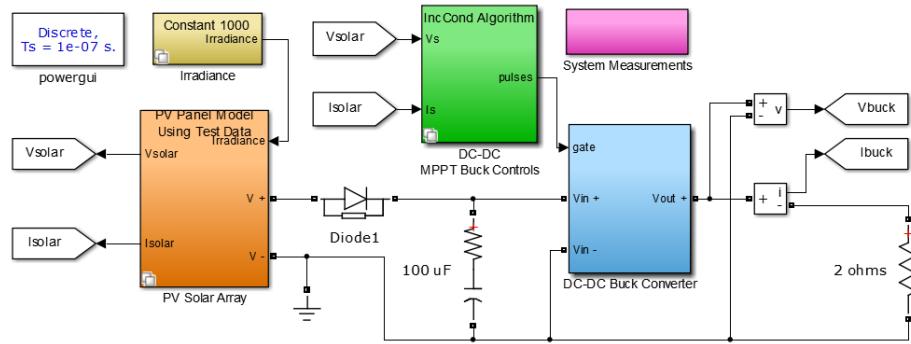


Fig. 2. Simulink model of PV system

The five parameter model of PV solar array sources using experimental test data and the data for block PVVI Curves 2D Lookup Table is depicted in Fig. 3, and the five parameter model of PV solar array using fundamental approaches of first principles Simulink is depicted in Fig. 4. These two PV solar array model have the same electrical parameters. The main parameters of the PV solar array are listed in Table 1.

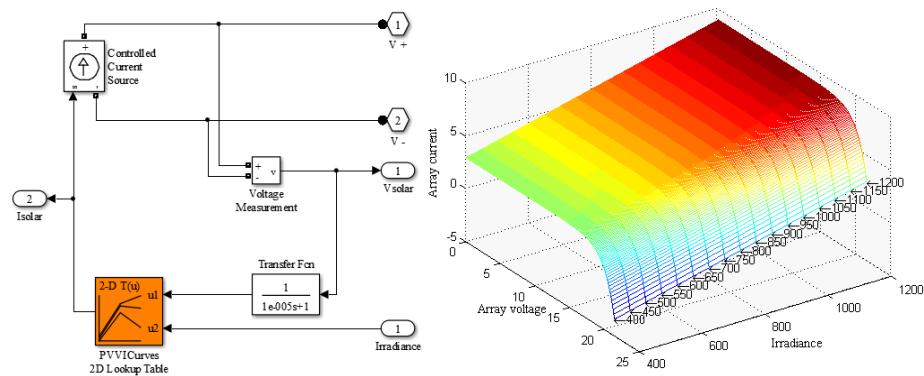


Fig. 3. Simulink block diagram of PV solar array source and respectively the block data of five parameter model of PV array using experimental G-V-I surface

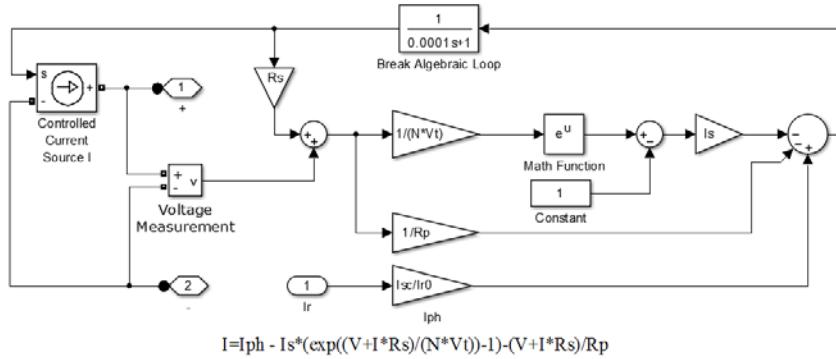


Fig. 4. Model of PV solar array source using first principles Simulink

Table 1

PV solar array parameters	
Parameter	Value
Short-circuit current, I_{sc}	7.34 (A)
Open-circuit voltage of PV solar array, V_{oc}	21.6 (V)
Series resistance of PV solar array, R_s	0 (Ω)
Parallel resistance of PV solar array, R_p	Inf (Ω)
Diode quality factor, N	1.5
Number of series connected solar cell, N_s	36

3. Result and discussions

This section shows the simulation results of PV solar array sources for the PV simulator presented in Fig. 2. This study follows the output power of a PV system and not the I-V characteristic curves of PV solar array in order to establish which of these two PV solar array models are more suitable as a source for a PV system.

In Fig. 5 are given the output power of PV solar panel for an irradiance (G) level of 1000 W/m^2 in case of PV solar array source current–voltage surface and respectively the case of PV solar array source realized using first principles Simulink. As can be seen from this figure in case of PV solar array model using experimental data (Fig. 3) the power obtain at the output of PV solar array are significant higher and data the power curve have smaller oscillations against case in that is used a solar array model realized using fundamental approaches of first principles Simulink (Fig. 4), that confirm the choice of PV solar array using experimental test data.

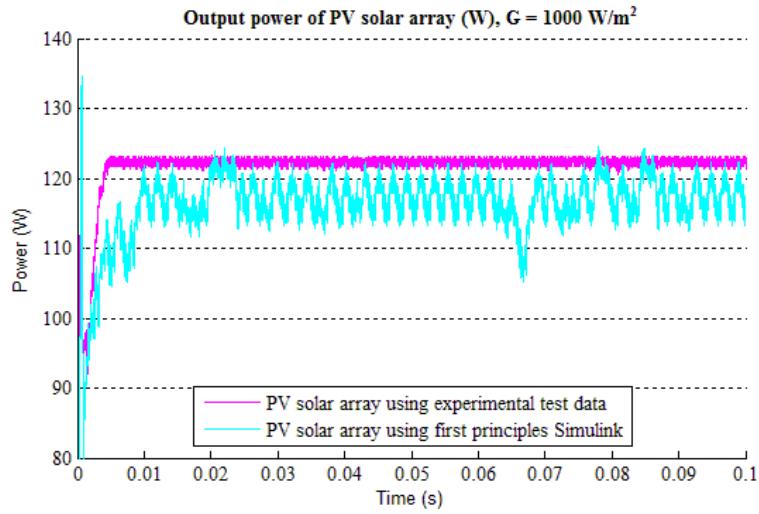


Fig. 5. Output power of PV solar array source using experimental G–V–I surface and respectively the five parameter model of PV solar array source using first principles Simulink

The output voltage and current for both models of PV solar array that are coupled to a load through a dc-dc step-down converter with MPPT controller (Fig. 3) are depicted in Fig. 6 and respectively in Fig. 7. As shown from these figures, at the output of PV solar array are obtained different voltages and currents and implicitly of powers (Fig. 5) as a result of the introduction of buck converter.

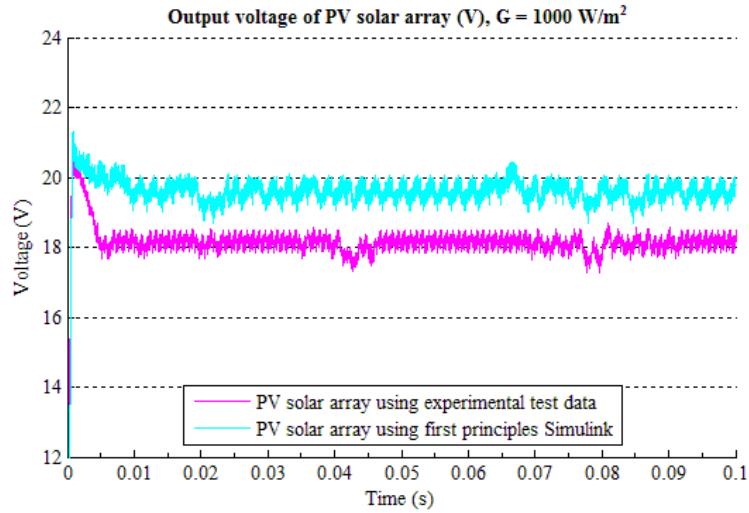


Fig. 6. Output voltage of PV array using test data and respectively using first principles Simulink

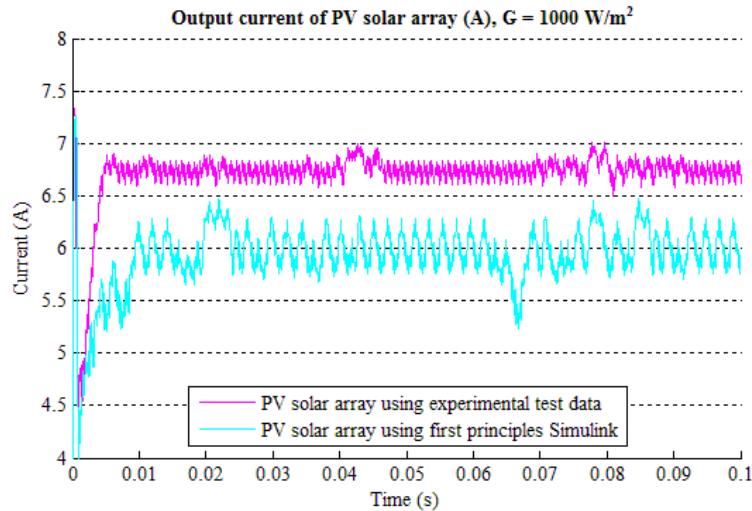


Fig. 7. Output current of PV solar array using experimental test data and respectively the five parameter model of PV solar array using first principles Simulink

In case of direct-coupled PV solar array simulations (without dc-dc converter and MPPT controller) at the same irradiance condition ($G = 1000 \text{ W/m}^2$), the output parameters values of PV solar array are close together for both models as indicated in Table 2. In case of PV system simulations the variations of the voltage, the current and the power at the output of PV solar array, that are presented in Fig. 5-7, are caused by incremental conductance algorithm of MPPT controller.

Table 2

Output parameters of direct-coupled PV solar array, $G = 1000 \text{ W/m}^2$

	PV solar array model using experimental test data	PV solar array model using first principles Simulink
Voltage (V)	15.32	15.36
Current (A)	7.26	7.27
Power (W)	111.2	111.7

6. Conclusions

This paper presents a study based on modeling PV solar arrays to determine the optimum five parameter model of PV solar module or array that has a behavior and current-voltage characteristic curves as close as possible to reality.

The two PV solar array sources relied on models for the PV solar array simulator with step-down dc-dc converter and MPPT control. Given that the PV solar array simulator was simulated for different solar array sources, and having as the argument the power obtained at the output of PV panel is decide the

superiority of PV solar array model using experimental data over the PV solar array model using fundamental approaches of first principles Simulink.

A possible applicability of this obtained results is the implementation in Matlab/Simulink of a PV simulator that has as its source a particular model of PV solar array which can be implemented with various types of circuit for solar cells, i.e. in this case a model with 5 parameters, that are used to simulate operation of a PV system in different conditions (irradiance, temperature, load profiles).

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