

A Comparative Analysis Of Different Photovoltaic Cells Models Based On Fundamental Modeling Approaches

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Abstract—This work focuses on multiple fundamental approaches used for modeling photovoltaic (PV) cells behavior and PV arrays one. Indeed, the PV cells models are generally designed using conventional mathematical equations. Afterward, the obtained PV model is simulated in Matlab/Simulink software using fundamental mathematical blocks and Simulink advanced library. In this paper, three PV model types are discussed. The first one is designed through the SimElectronics, in which a solar cell that is available in its library is used for modeling the PV cell behavior. The second PV model is performed using the Simscape library where physical components are adopted to describe the PV cell behavior. The last PV model is designed through some conventional mathematic equations describing a single PV cell behavior, in which some mathematical operator library and functions are used. Furthermore, all previous PV models allow predicting the PV cell behavior under different physical and environmental parameters. They allow also highlighting the flexibility of Simulink and the advantages of using the physical modeling libraries. Finally, the simulation results which validate the proposed models are presented.

Keywords— PV cell, Simulink, Simscape, Simelectronics, PV model.

I. INTRODUCTION

The growing energy demand with the possibility of reduced supply of conventional fuels, proved by high petroleum prices, along with growing concerns about polluting effects on environment, has driven researchers and their developments to alternative energy sources which are cleaner, renewable and produce less environmental impact. Among the alternative sources, solar energy is one of the most used and readily available renewable energy sources. Solar energy supplied by the sun in one hour is equal to the energy required by the human population in one year. Power generated by PV module depends upon the solar irradiation.

It is observed from various studies, that mathematical models of few individual components of PV system are modeled and simulated for better understanding of their performances. Indeed, the most important component that affects the precision of the simulation is the PV cell modeling. With this model, we can estimate of the I-V and P-V characteristics. However, no specific mathematical models of PV module exist for all applications. The development of PV system has required simulation tools able to control the mathematical model. Simulations have facilitated the process of developing and estimation of new systems using PV energy, by reducing cost and time. In this context, during these last years, many research laboratories focused on the modeling methods for solar PV, and important renovations have been achieved on this theme [1-6]. It may be clear from the literature there have been a number of modeling options starting from equivalent circuit equations which have been researched for PV cells, trading off accuracy with complexity. The single diode model is the most popular PV cell model used by researchers due to its simplicity and flexibility during parameter estimation [7-8]. Matlab simulink provide many ways of modeling devices or components or modeling complex systems. This paper presents a comparative study between multiple fundamental approaches that can be used for modeling photovoltaic cells. The studied methods used for comparison in this paper include Simulink implementation using mathematical blocks, Simscape and Simelectronics libraries. This paper has basically three sections. The first section presents a description of modeling single-diode solar cell. In the second section are described how the PV solar array are modeled using the methods cited above. The results and discussions regarding simulation of PV system are also

presented. Finally, in the last section of paper are presented the main conclusions of this study.

II. PV CELL MODEL

PV systems are broadly characterized by circuit-based approaches. For modeling a PV system under the illumination, the simplest way is to consider a current source in parallel to a diode. Consequently, three unknown parameters, namely, photo generated current (I_{ph}), diode saturation current (I_{sd}) and diode ideality factor (n), make the parameters of the equivalent circuit model. For considering the PV cell metal contacts, an improved model, takes into account a series resistance (R_s) to the model. Though R_s -model is more accurate, it shows serious deficiencies under high temperature variations since it does not account for the open circuit voltage coefficient. Another modification was suggested by adding a shunt resistance (R_{sh}) to the diode to consider the partial short circuit current path near the cell's edges resulted from the semiconductor impurities and non-idealities. This type of the model is known as the single diode model. In the single diode model, shown in Fig. 1, the terminal current can be formulated as follows [1-4]:

$$I_{pv} = I_{ph} - I_d - I_{sh} \tag{1}$$

Where I_d is the diode current and I_{sh} denotes the shunt resistor current. By use of Shockley equation for the diode current and substituting the shunt resistor current, Eq. (1) is rewritten as given in the following equation:

$$I_{pv} = I_{ph} - I_{sd} \left[e^{\left(\frac{q(V_t + R_s I_{pv})}{nkT} \right)} - 1 \right] - \frac{(V_t + R_s I_{pv})}{R_{sh}} \tag{2}$$

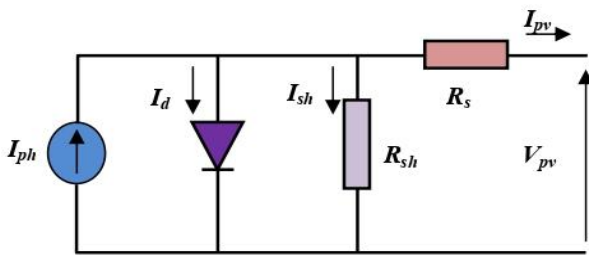


Fig 1. The single diode model of PV cell

Where I_{sd} is the diode saturation current, V_t is the terminal voltage, q is the electronic charge, k denotes the Boltzmann constant, n is the diode ideality factor and T ($^{\circ}K$) is the cell temperature. When insolation drops, short-circuit current of cell drops in direction proportion. A PV module consists of series and parallel PV cell combinations.

In practice photocurrent I_{ph} is dependent on actual and standard irradiance (G and G_{ref}) and solar cell operating and

standard temperature (T and T_{ref}) according to the following relation:

$$I_{ph} = \frac{G}{G_{ref}} [I_{sc,ref} + K_i(T - T_{ref})] \tag{3}$$

With $I_{sc,ref}$ is the cells short-circuit current provided by manufacturer at standard temperature ($25^{\circ}C$), K_i is temperature coefficient of the short circuit current.

III. SIMElectRONICS SIMULATION MODEL FOR A SOLAR CELL

SimElectronics is part of the Simulink Physical Modeling family, providing component libraries that include semiconductors, motors, drives, sensors, and actuators. To build electromechanical and electrical models, a combination of SimElectronics blocks and other Simscape and Simulink blocks can be used. These blocks are used to optimize system-level performance and to create installation templates for control design. Fig.2 shows the symbol of solar cell in SimElectronics. In its library, this block represents a single solar cell as a parallel current source I_{ph} , an exponential diode D and a shunt resistance R_{sh} , that are connected in series with a resistance R_s .

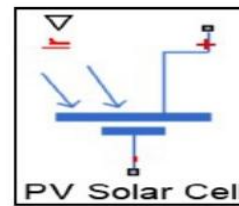


Fig. 2. Symbol of a Solar cell under SimElectronics environment

The SimElectronics model used for simple solar cell simulation is shown in Figure 3. The block of the PV cell (see Fig. 2) uses the five-parameter model with the impedance of parallel resistance being infinite. The model chosen makes it possible to optimize this block according to the parameters of the equivalent circuit model or the short-circuit current and the open-circuit voltage [8-13].

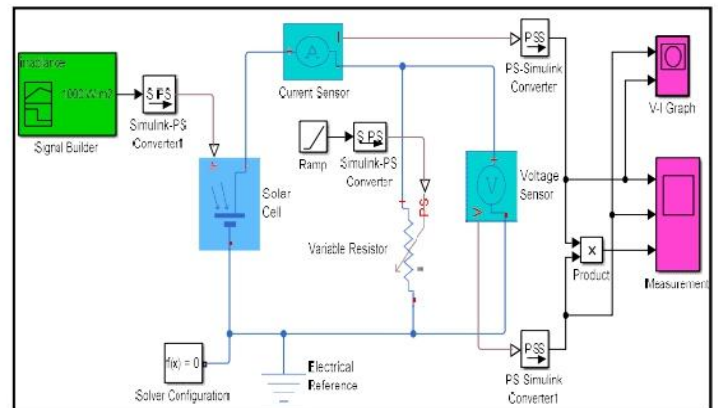


Fig. 3. SimElectronics Simulation Model for a single Cell

The model shown in fig.3 was developed using blocks of SimElectronics and Simulink. In fact, the solar cell is connected to the current and voltage sensor blocks to measure current and voltage in the solar cell. In addition, an irradiance block is also connected in the above model. The other blocks formed the interface between the main blocks and were used to plot the I-V characteristics.

The solar cell was parameterized by equivalent circuit parameters. Diode reverse saturation current, I_s , was taken as $0.1nA$, measurement temperature was kept as $25^{\circ}C$. Solar-generated current, I_{ph0} , and Irradiance used for measurements, G_0 , were kept at their default values of $7.34A$ and $1000 W/m^2$ respectively. The photovoltaic cell model is validated by simulating at a value of irradiance of $1000W/m^2$ and a temperature of $25^{\circ}C$.

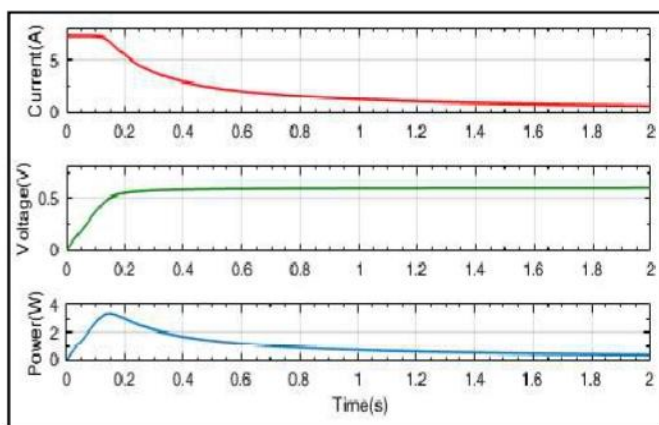


Fig. 4 Current, voltage and power curves for PV cell

Figure 4 shows the current, voltage and power curves of the photovoltaic cell. When the resistance of the load varies, the current, voltage and power faithfully describe the behavior of the PV generator

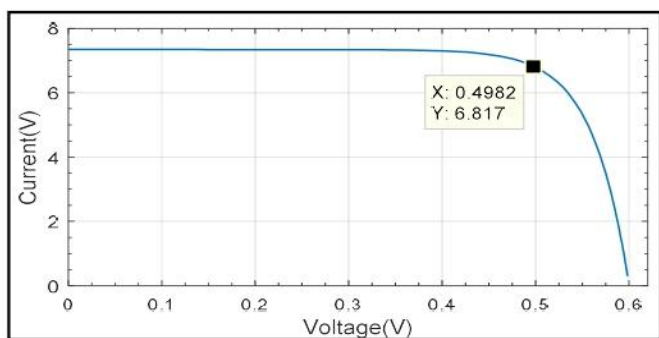


Fig. 5. The I-V characteristics of the photovoltaic cell.

The I-V characteristics of the photovoltaic cell is given in Figure 5. It represents the standard behavior of the photovoltaic cell. In the middle of this characteristic is the maximum power point. This point is very critical for this kind of system for maximum power extraction from the

photovoltaic system. This result that, the main objective is to try operating around of this maximum point in order to make the photovoltaic cells to work at maximum efficiency.

A. Variation in irradiance

Fig.6 shows the I-V and P-V characteristics .The simulation was performed for Irradiance which vary in steps of $300W/m^2$ from $400 W/m^2$ to $1000 W/m^2$. The Circuit temperature (SimElectronics Environment Parameter) was kept at $25^{\circ}C$.

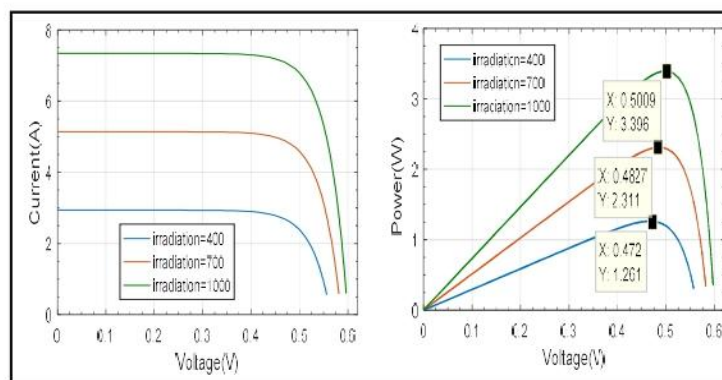


Fig. 6. Characteristic: Current, Power = f (Voltage) for different illuminations

It is observed that the photocurrent varies with irradiance and the percentage change in short circuit current (I_{sc}) is much more than the percentage change in open circuit voltage (V_{oc}).The current changes from $7.3A$ to $2.9A$ and power from $3.39W$ to $1.26W$. The output power is higher for high irradiance value.

TABLE I
IRRADIANCE VARIATION

Irradiance(W/m^2)	400	700	1000
$V_m(V)$	0.472	0.4827	0.5009
$P_m(W)$	1.261	2.311	3.396

IV. MODEL USING PHYSICAL ELEMENTS

This model is developed using the Simscape library where physical components are adopted to describe the PV cell behavior. The circuit contains (a current source, two resistors and a diode); the equivalent circuit diagram of the solar cell is represented by the fig.7.

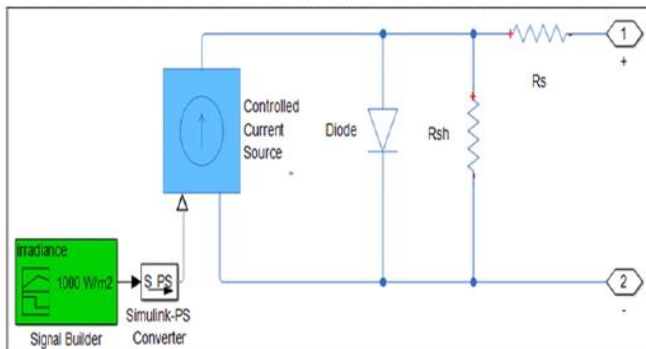


Fig.7. Equivalent circuit of a cell in Simscape environment

The complete simulation model of solar PV cell is shown in Fig.8. It consists of three main blocks, namely: PV cell block, sensors block and load block.

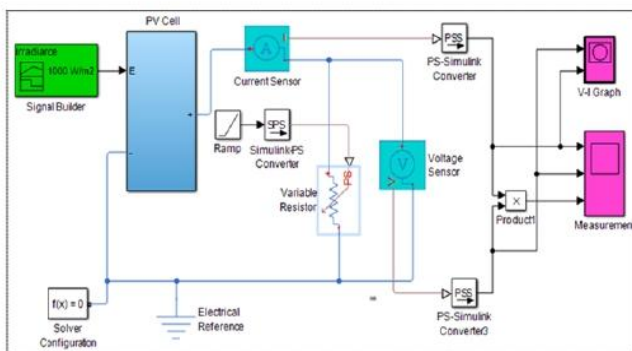


Fig.8. Modeling of the PV cell under the environment Simscape

Figure 9 shows the current, voltage and power which are obtained at output of PV cell. These curves are given versus time. As soon as the resistance varies, the current and voltage vary depending on the voltage-time relationship which gives the power curve.

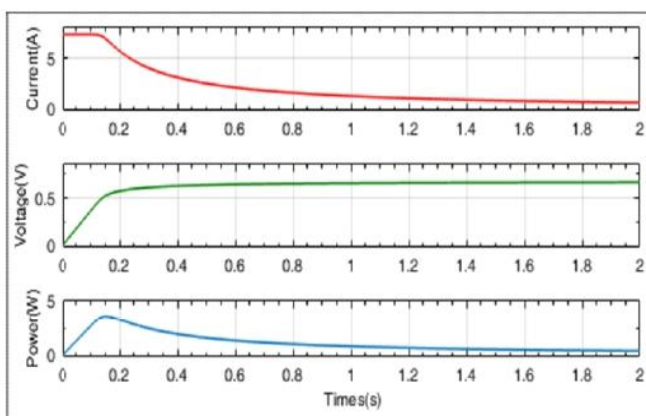


Fig. 9. Current, voltage and power curves for PV cell

Fig.10 shows the I-V characteristic of a PV cell under STC conditions of 25°C temperature and 1000 W/m² of irradiance.

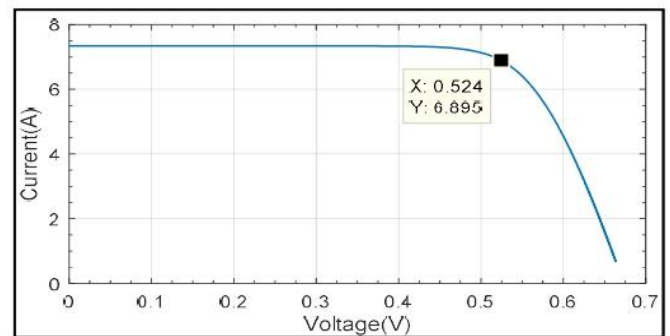


Fig. 10. The I-V characteristics of the photovoltaic cell.

In fig.11 the PV cell output current and power are greatly influenced by the change in radiation, whereas the output voltage stays approximately constant. There is a unique point in which the solar module is said to operate at maximum efficiency and produces its maximum output power (P_m) corresponds to a specific current (I_m) and voltage (V_m). This point also changes with environmental conditions.

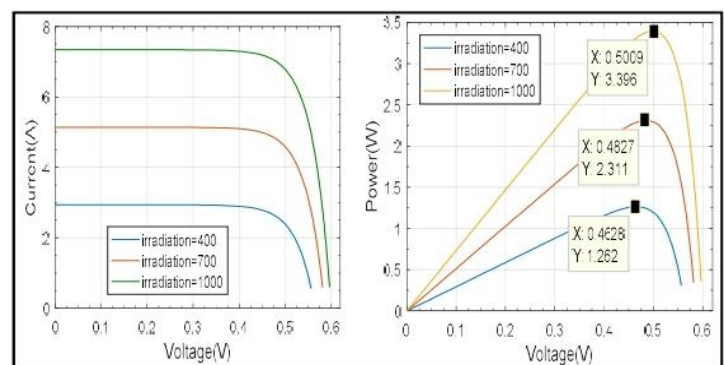


Fig.11. Characteristic: Current, Power = f (Voltage) for different illuminations

B. Variation in irradiance

From Fig. 11 and Table 2, it can be observed that the irradiance value impacted the short-circuit current (I_{sc}) as well as open-circuit voltage (V_{oc}) but more affected was the value of (I_{sc}). As irradiance value increased, the short -circuit increased and the maximum power P_m also increased.

TABLE II
IRRADIANCE VARIATION

Irradiance(W/m ²)	400	700	1000
V_m (V)	0.4628	0.4827	0.5009
P_m (W)	1.262	2.311	3.396

V. MODEL USING FUNCTION IN SIMULINK

By using general model (see fig.1) and applied equations (1) and (2), we have established the block of the PV generator in SimPowerSystems/ Simulink which is represented in fig.12.

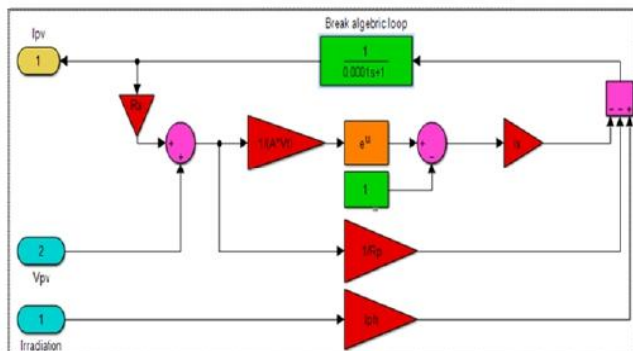


Fig. 12. Model of PV solar cell using Simulink /SimPower System.

The Simulink Simulation Model for a single Cell using SimPower System is represented by Fig.13. It contains a Solar cell which is connected to the variable resistor through current sensor and voltage sensor. The Simulink converter blocks provide the current and voltage of solar cell to the measurement blocks.

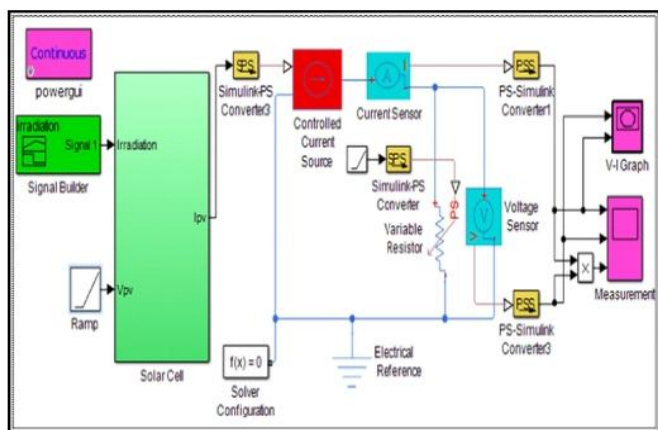


Fig. 13. Simulink Simulation Model for a single Cell

Fig. 14 also confirms the behavior expected from a solar cell: its current and voltage vary depending on the voltage-time relationship which gives the power curve.

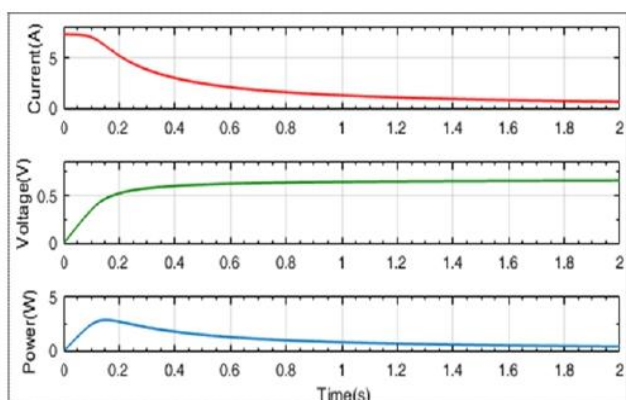


Fig. 14. Current, voltage and power curves for PV cell

The I-V characteristic is shown in fig.15. The curve indicates the solar cell maximum voltage and maximum output current at 25°C temperature and for an irradiation of 1000 W/m².

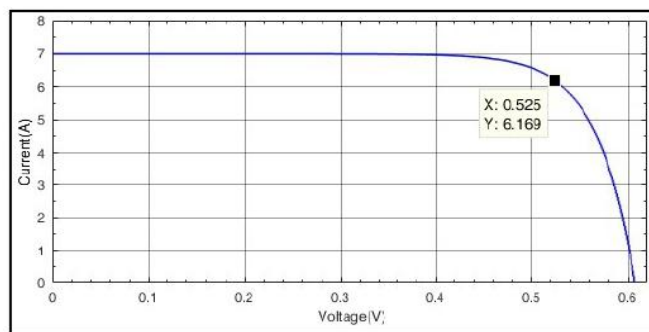


Fig. 15. The V-P characteristics of the photovoltaic cell.

C. Variation in irradiance

In Figure 16 are given the P-V characteristics for different levels of solar radiation at the temperature of 25°C. From this Figure, it is observed that for an irradiance of 700 W/m², which corresponds to red curve is obtained a maximum power of 2.233W and for an irradiance of 1000 W/m² which corresponds to green curve, the PV cell provide a maximum power of 3.283 W. That gives an idea of measure in the power produced by a photovoltaic cell is affected by changing irradiance.

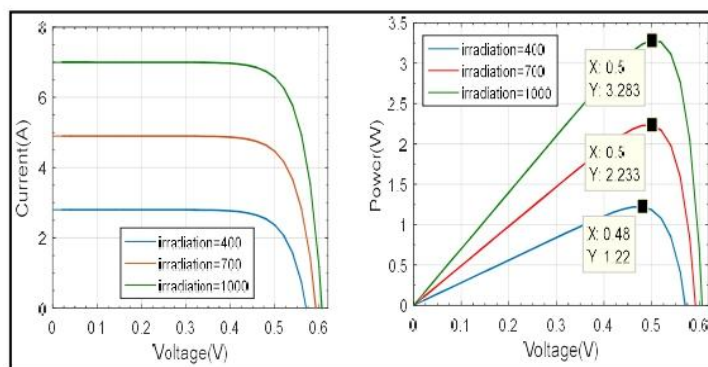


Fig.16. Characteristic: Current, Power = f (Voltage) for different illuminations

TABLE III

IRRADIANCE VARIATION

Irradiance(W/m ²)	400	700	1000
V _m (V)	0.48	0.5	0.5
P _m (W)	1.22	2.233	3.283

VI. CONCLUSION

In this paper model for simulation of a solar cell has been developed in Simelectronics, simscape and mathematical

blocks in MATLAB/Simulink environment using solar cell block and other interfacing blocks. In all the simulations, it could be observed that the power produced by a photovoltaic cell is affected by changing irradiance. So, it can be said that MATLAB with integrated library, can be used to simulate photovoltaic solar cells under different conditions and can substitute for expensive experiments on actual solar cells. The simulation results validate the proposed model. This developed model can also be used for modeling of large PV power system.

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