

## Simscape Solar Cells Model Analysis and Design

MOHAMMED S. IBBINI<sup>1</sup>, SHADI MANSI<sup>2</sup>, MOHAMMED MASADEH<sup>3</sup>, EID AL HAJRI<sup>4</sup>

<sup>1</sup>Electrical Engineering Department  
Jordan University of Science and Technology  
P.O. Box 3030, Irbid 22110  
JORDAN  
mohib@just.edu.sa

<sup>2, 3 and 4</sup> Electrical & Electronic Engineering Technology  
Jubail Industrial College  
P.O. Box 10099, Jubail Industrial City 31961  
SAUDI ARABIA

*Abstract:* - Sometimes it is required to study the characteristics and behavior of the PV system under different connections or conditions without going deep in its hideous mathematical presentation. It is only needed to focus on the research idea rather being lost in the different PV equations and demonstrations. However, it is still required to monitor how the system will react to different effects and to carefully record system variables such as voltage, current, and power. MATLAB/Simulink presented a powerful tool to study such systems. Simscape, part of Simulink environment, has a solar cell block that makes building a PV model straightforward and much easier programming with full demonstration to all system details. This manuscript is made to be used as a tutorial to those who are new in this field and to highlight the most important works done using the this model.

*Key-Words:* - Solar Cells, PV Module, MATLAB/Simulink/Simscape, physical modelling language.

### 1 Introduction

Developing a mathematical model for a physical system is an indispensable tool to effectively design a control system and accurately predict its performance. Usually, the model complexity is related, in some degree, to the physical system nature and the way it interacts to the surroundings. In many cases, other structures are added to the original system to convert the output power into adequate functioning form. These extra structures are called signal conditioning systems and they are famous by their non-linearity and discrete signals. This will add more difficulties to capture system behavior and, hence, makes the modeling more challenging. This case is literary applies to the Photovoltaic (PV) systems.

To investigate the performance of a PV generation system, full detail knowledge to the PV cell characteristics is required to develop a reliable equivalent circuit. Moreover, it is still needed to experimentally verify the I-V curve and extract the necessary parameters to build the equivalent PV model [1, 2]. No solar system works without the power electronics circuits. They are used to ensure extracting the maximum power from the solar

generation units and convert the DC power to a form that suits the load needs.

Many mathematical models and equations were proposed in literature to simulate the performance of the photovoltaic cell [3-8]. Obviously, the most common are the single-diode and the two-diode models [9]. These models are excellent tool to predict the effect of external conditions such as irradiance, shadow, and temperature on the generated power. Obviously, such work requires deep understanding and familiarization to system physics. Any missing parameter will effect on the model reliability, and hence, the analysis of system performance will not be valid. One explicit example to PV system is badly considering the inner parameters of the module like internal resistances and diode specifications.

However, the field of power conversion needs this model but without getting involved in the semiconductor details [10]. It is required to size then build the system arrays and study its reaction towards load or grid sudden and sever changes. Although it is important to monitor the dynamics of the generated power elements in the PV system side, the solar cell itself is not the target for investigation.

MATLAB's Simscape modeling environment [11] offers the option of ready-made blocks to imitate real physical components. Recently, researchers were attracted to use Simscape language and explore its ability to model and simulate or even analyze stability for power generation systems [12]. Others investigated and realized the PV systems models based on Simscape [13, 14, 15]. Moreover, Simscape was found as a powerful instrument to depict the effect of the environment on the generated power and the terminal characteristics of a PV panel. [16, 17, 18] for instance, explored the shading effect; and [19] analyzed the hotspot phenomenon. Lately, some modest works tried to examine how the PV Simscape model would react if it is connected to a grid [20, 21].

This work is made to highlight the strong points for the usage of Simscape solar cell model and present the literature which used it. The paper is organized as follows: Section 2 presents the main differences between Simscape and Simulink. Section 3, describes in details the best way to build and model a PV module starting from the solar cell then it explains how to extract the terminal characteristics of the module affected by environmental conditions. Building an array and studying the shadow effect will be illustrated in section 4. Finally conclusion is given in section 5.

## 2 How Simscape is Different from Simulink

Simulink is a graphical programming language where input and output blocks are connected together to represent a dynamic system. It is required to derive and verify the mathematical equations first and then convert them into blocks demonstration. This type of programming presents the flow of signal between the blocks ports and yields to a unidirectional signal-based mathematical model [12]. In short, Simulink is a traditional language which converts the modeling equations into block diagram representation.

On the other hand, Simscape is a physical modelling language used to present mathematical models of physical components. It provides basic blocks from different physical domains such as electrical, mechanical, hydraulic, pneumatic, thermal, etc. [22]. The model can be constructed, as in Simulink, by assembling the building blocks together to build a complete system with the ability to have different domains. However, the concept of programming in Simscape is totally different from that of Simulink. The main difference is, Simscape

blocks consist of functional elements that interact with each other by exchanging energy through their bidirectional connection ports [11]. This means that "the behavior of every port will be handled automatically as long as the "energy conservation principle" is preserved" [12]. The number of connection ports for each element is determined by the number of energy flows to exchange with other elements in the system. This concept will be depicted in this article when it comes to study the behaviour of a shaded solar cell. It will be noticed that the cell current can take two directions, either generated out the cell, or moves through it based on the cell condition. It is hard to capture this energy concept in the Simulink solar model since the cell, or PV module, is considered as a current source.

Connecting Simscape to Simulink blocks and vice versa is an interesting subject where the advantages of these to programming languages will be considered. Based on the fact that both languages have different signal nature, it is not possible to overlap or connect their blocks directly. As a result, transitional structures must be used for this purpose. In fact, there are two types of intermediate blocks depending on the function and use of the signal. The first one is the converters which are basically used to connect Simscape diagrams to Simulink sources and sinks. While the interfaces blocks are used to couple between SimPowerSystems and Simscape electrical circuits.

Finally, it must consider the fact that each physical network represented by a connected Simscape block diagram requires solver settings information for simulation. The Solver Configuration block specifies the solver parameters that a model needs before it begin simulation. Each topologically distinct Simscape block diagram requires exactly one Solver Configuration block to be connected to it.

## 3 Modeling

The PV cell is the basic element to build a PV module. Matlab/Simulink developed a PV cell block in Simscape environment to simulate the exact behavior of a real cell. These cells blocks can be grouped in parallel and series formulation to construct a module. As an example, Fig. 1 shows eight cells connected in series to construct a string. Although Fig. 1 illustrates that these cells can interact with irradiance as the only input, the cell's temperature can be also considered as one of the configurable parameters. This also applies to the internal resistances  $R_s$  and  $R_p$ .

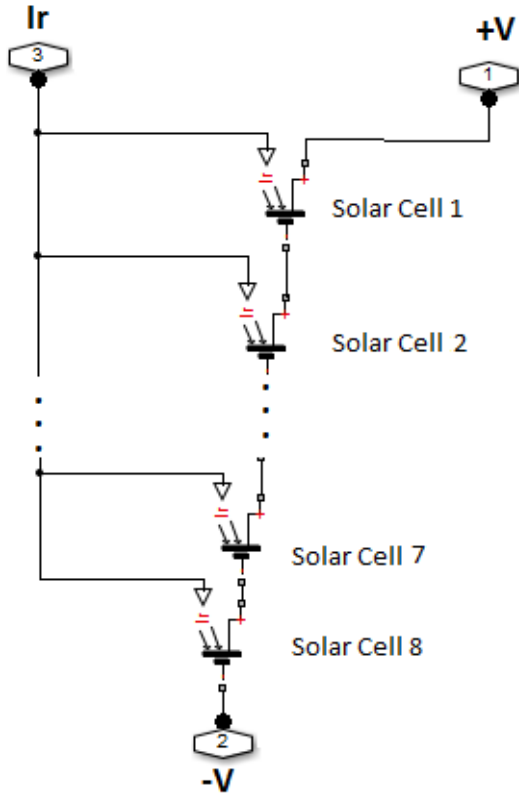


Fig.1: 8 solar cells connected in series.

"The Simscape block models a solar cell as a parallel combination of a current source, two exponential diodes and parallel resistor,  $R_p$ , that are connected in series with a resistance  $R_s$ . The output current" [11],  $I$ , is given by [10]:

$$I = I_{ph} - I_{s1} \left[ e^{\frac{V+IR_s}{KT}} - 1 \right] - I_{s2} \left[ e^{\frac{V+IR_s}{AKT}} - 1 \right] - \frac{V + IR_s}{R_p} \quad (1)$$

Equation (1) can be simplified as:

$$I = I_{ph} - I_s \left[ e^{\frac{V+IR_s}{AKT}} - 1 \right] - \frac{V + IR_s}{R_p} \quad (2)$$

The string presented in Fig. 1 can be repeated, based on the module specification, to form a PV module. Fig. 2 shows four strings of solar cells grouped together to construct a module. The module will have one input, irradiance in  $W/m^2$ , and two voltage polarity outputs, +V and -V. Obviously; it works as a voltage source, or a battery, which can be connected later in series and parallel with other similar sources to form an array. The elements in Fig. 2 can be assembled together under one mask, as shown in Fig. 3, and then connected to a dynamic load. The load will be varied from 0 up to max to

represent both short-circuit and open circuit conditions. This will help to study the output characteristics of the system.

The terminal characteristics of the PV module are the P-V and I-V curves which can be generated from Fig. 3. It is important to study the influence of the environmental effects on these curves. For instance, the maximum power will be dramatically changed as surrounding conditions vary.

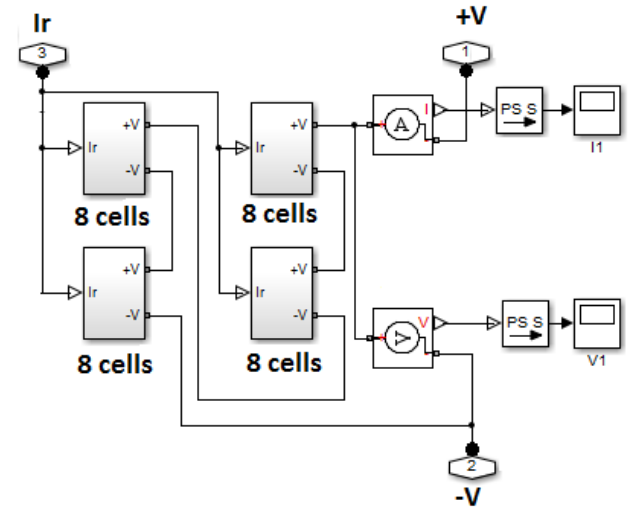


Fig.2: Four groups of 8 cells for each to configure a PV module.

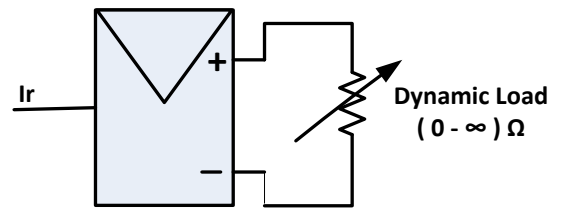


Fig.3: A PV module created from 32 series PV cells and connected to a dynamic load.

The irradiance will take place in equations (1) and (2) by considering the parameter  $I_{ph}$ , the photo-generated current, which is already in linear relation with irradiance as follows:

$$I_{ph} = I_{ph0} \frac{I_r}{I_{r0}} \quad (3)$$

where  $I_r$  and  $I_{r0}$  are the irradiances in  $W/m^2$  for the real irradiance affects the cell and the standard irradiance respectively. The Simscape solar cell module has a dedicated input for the irradiance as shown in fig. 3. Fig. 4 shows the terminal characteristics of the already built PV module through the P-V and I-V curves when the module is subjected to different irradiances.

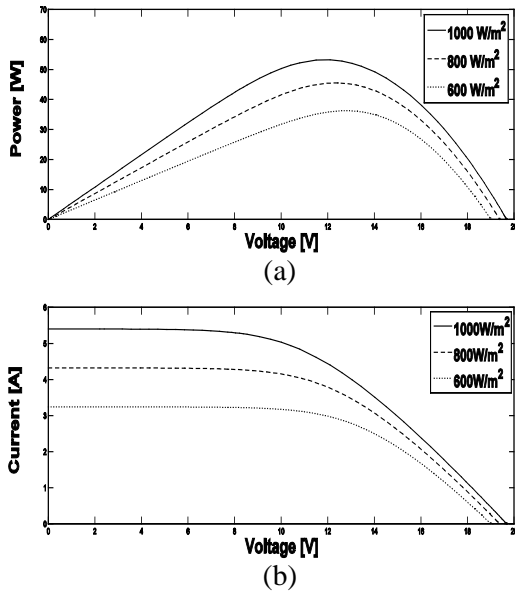


Fig.4: (a) P-V curve and (b) I-V curve of a PV module under different irradiance.

Moreover, temperature is an environmental parameter with a significant effect on the module performance. It is represented in equations (1) and (2). However, more sophisticated manipulations are needed to accurately present the temperature effect [10]. These operations are managed in the Simscape module and the results are shown in Fig. 5. Although the temperature is not an input to the module, this parameter is deliberated in the cell configuration window. It can be saved in the MATLAB workspace and changed from there while the simulation is running to study its effects.

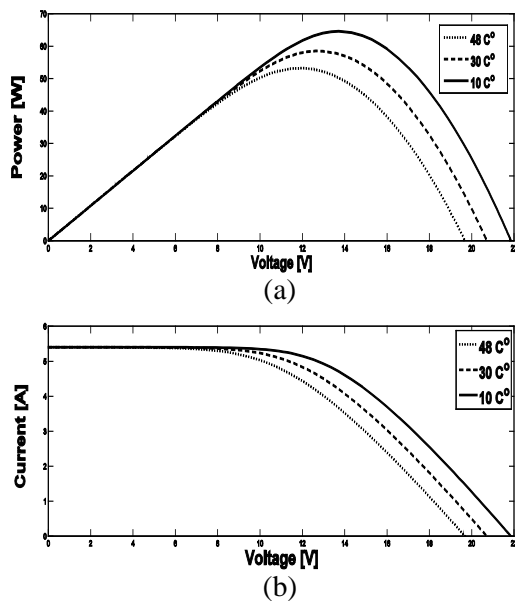


Fig.5: (a) P-V curve and (b) I-V curve of a PV module under different temperature.

Another important parameter which should pay attention to is the internal resistance of the module. Unfortunately, PV manufacturers don't provide all data needed to construct the model. This includes the internal resistance which plays a major role to determine the module performance. Many methods were proposed in literature to verify the resistances values experimentally, but it is beyond the scope of this work, so, it will not be discussed here. However, it is still a substantial subject to consider these values in the model and not to ignore them. Fig. 6 shows same module performance with different  $R_s$  values. Apparently, a model without considering the resistance will predict much higher power than the one with the actual value, and this will affect the model reliability. Again Simscape solar cell block considers the internal resistances same as the temperature parameter which was discussed before.

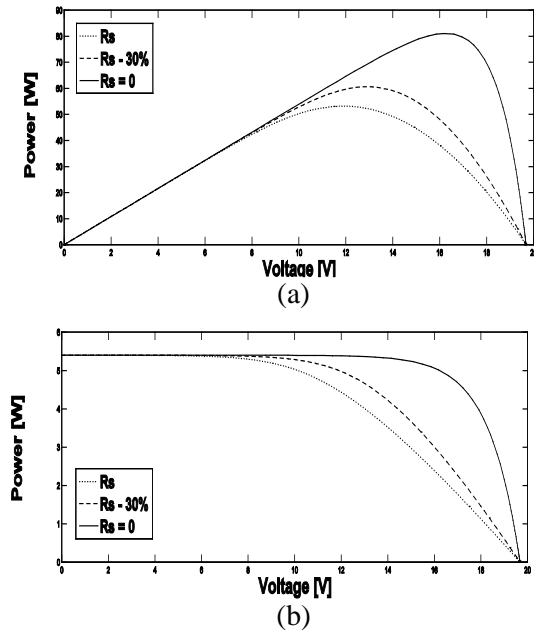


Fig.6: (a) P-V curve and (b) I-V curve of a PV module with different  $R_s$  internal resistance values.

#### 4 Shadow Effect

It has always been a challenging work to study the performance of a large PV-array generation system under ununiformed distribution for the environmental conditions. It is used to assume that the whole modules will be similarly affected by such circumstances. This can be done, roughly, by manipulating the output generation values, voltage and current, with the number of arrays. However, if the PV-array power size is big, reaches kW or MW, then similarity condition is not valid any more. Definitely, as the power size increases, the needed

area covered by modules will proportionally increase too. This leads to the fact that not all modules will be exposed to similar conditions.

Partial shading, which is a result of partly cloudy array, is an example of this case. The unavoidable shadow will seriously affects the PV performance and the harvested power which can be obtained. Moreover, partial shading causes hot spot in the corresponding cells and causes severe damage to it. Different models were suggested, [17, 18, 19] as examples, to study the shaded cases of the PV module with diverse of connections topologies. Fig. 7 shows PV modules connected in series and parallel to be investigated.

The whole system can be easily modeled using Simscape. This can be done by copying the module shown in Fig. 3 and connecting it based on the topology wanted as in Fig 7. Since each module will have its own irradiance input then shading presentation will be an easy task to do. The Simscape environment will help to extract the data and analyze it. For example, Fig. 8 displays the performance of the series connected modules with one shadow case.

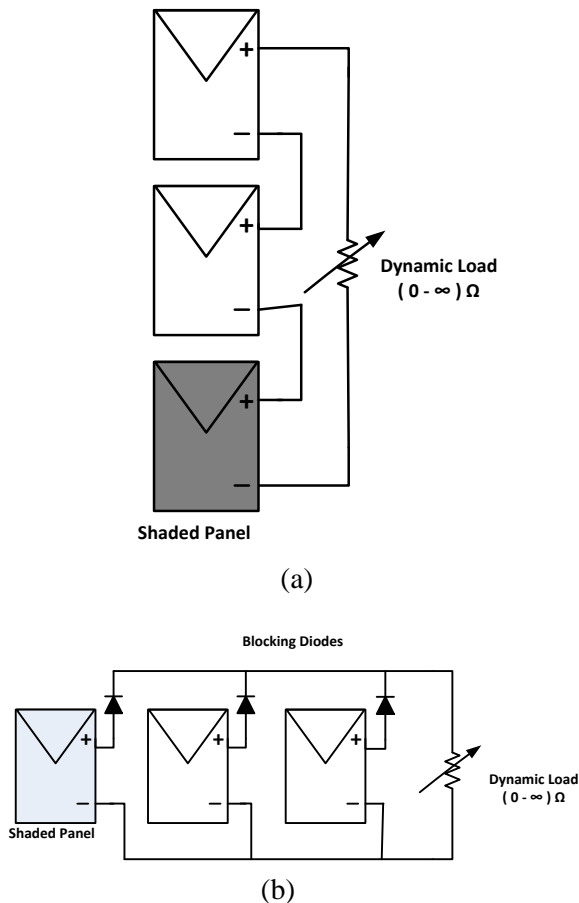


Fig.7: Two different connection topologies for three symmetrical modules connected (a) in series, (b) in parallel.

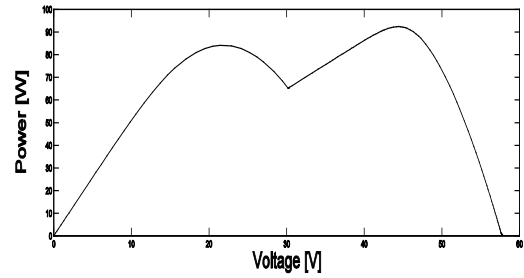


Fig. 8: Series connected module performance with shadow effect

Furthermore, the effect of adding extra electronic components like the blocking diode, shown in Fig. 7 (b), can be easily investigated. Fig. 9 illustrates the performance of the parallel connected modules with and without the blocking diodes. Moreover, it deserves to notice that even of the solar cell was considered as a current source; the fact that the current direction can be changed based on the "energy conservation principle" discussed in section 2 is implemented. Since the modules are acting as power sources connecting in parallel, and one of them will have less voltage caused by the shadow effect then it is expected the current will have negative direction in that particular module. Again, this is easy to be done in Simscape module since it is emulating a real physical system. Fig. 10, shows the effect of having the blocking diodes in the shaded module

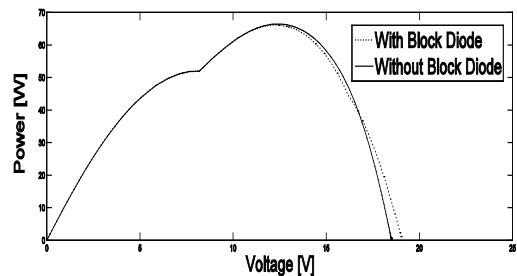


Fig. 9: Parallel Connected module performance with shadow effect.

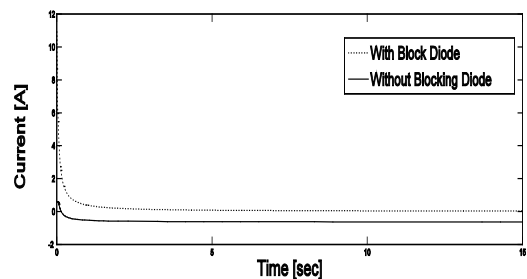


Fig. 10: The current moves through a shaded module with and without blocking diodes.

## 5 Conclusion

It was found that PV Simscape model is an easy tool to simulate the PV systems. It helps to focus on the main ideal of the work with seizing all dynamic output variables of the solar cells. The power of the Simscape model is that it starts the modelling from the basic elements and then builds up the whole physical system. Although literature examined and covered some PV system conditions using Simscape but still there is a vacancy in the room. Simscape grid-connected PV models need to be more examined more. The way the Simscape and SimPowerSystems connecting to each other also requires more modifications to gain the advantages of both systems. Moreover, voltage stability and MPPT not well investigated and needs more contributions.

### References:

- [1] Marcelo Gradella Villalva, Jonas Rafael Gazoli, and Ernesto Ruppert Filho, Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays, *IEEE Transactions on Power Electronics*, VOL. 24, NO. 5, MAY 2009, pp. 1198-1208.
- [2] Po-Wen Hsiao, Chih-Hao Chang, Huan-Liang Tsai, Accuracy Improvement of Practical PV Model, *SICE Annual Conference 2010*, Taipei, Taiwan, pp. 2725-2730.
- [3] Mohammad Seifi, Azura Bt. Che Soh, Noor Izzrib. Abd. Wahab, and Mohd Khair B. Hassan, A Comparative Study of PV Models in Matlab/Simulink, *World Academy of Science, Engineering and Technology* 74 2013, pp. 108-113.
- [4] Keles ,C .; Alagoz, B.B. ; Akcin, M. ; Kaygusuz, A. ; Karabiber, A., A photovoltaic system model for Matlab/Simulink simulations, *Fourth International Conference on Power Engineering, Energy and Electrical Drives (POWERENG)*, 2013, pp. 1643 – 1647.
- [5] Huan-Liang Tsai, Ci-Siang Tu, and Yi-Jie Su, Development of Generalized Photovoltaic Model Using MATLAB/SIMULINK, *Proceedings of the World Congress on Engineering and Computer Science (WCECS)* 2008, San Francisco, USA, pp. 1-6.
- [6] J. Surya Kumari and Ch. Sai Babu, Mathematical Modelling and Simulation of Photovoltaic Cell Using MATLAB/Simulink Environment and PLECS Blockset, *International Journal of Electrical and Computer Engineering (IJECE)*, Vol. 2, No. 1, February 2012, pp. 26-34.
- [7] Tarak Salmi, Mounir Bouzguenda, Adel Gastli, Ahmed Masmoudi, MATLAB/Simulink Based Modelling of Solar Photovoltaic Cell, *International Journal Of Renewable Energy Research*, Vol.2, No.2, 2012, pp. 213-218.
- [8] Jenifer .A, Newlin Nishia.R, Rohini.G3 Jamuna. V, Development Of Matlab Simulink Model For Photovoltaic Arrays, *International Conference on Computing, Electronics and Electrical Technologies [ICCEET]* 2012, pp. 436-442.
- [9] Soliman A. Mahmoud, Mejd M. Alsari, Esra I. Reda, and Ruqiya M. Alhmmadi, MATLAB Modeling and Simulation of Photovoltaic Modules, *IEEE 55th International Midwest Symposium on Circuits and Systems (MWSCAS)*, 2012, pp. 786-789.
- [10] J. A. Gow, C. D. Manning, "Development of a Photovoltaic Array Model for Use in Power-Electronics Simulation Studies", *IEE Proceedings of Electric Power Applications*, Vol. 146, No. 2, March 1999, pp. 193–200.
- [11] [www.mathworks.com](http://www.mathworks.com)
- [12] Li Changsong, Development of Simscape Simulation Model For Power System Stability Analysis, *Asia-Pacific Power and Energy Engineering Conference (APPEEC)*, 2012, pp. 1-4.
- [13] Suskis, P., Galkin, I., Enhanced Photovoltaic Panel Model For MATLAB-Simulink Environment Considering Solar Cell Junction Capacitance, *39th Annual Conference of the IEEE Industrial Electronics Society, IECON* 2013, pp. 1613 – 1618.
- [14] VandanaKhanna, Bijoy Kishore Das, Dinesh Bisht, MATLAB/SIMELECTRONICS Models Based Study of Solar Cells, *International Journal of Renewable Energy Research*, 2013, pp. 30-34.
- [15] Sahoo, N.C. Elamvazuthi, I.; Nor, N.M.; Sebastian, P. PV Panel Modelling Using Simscape, *International Conference on Energy, Automation, and Signal (ICEAS)*, 2011, pp.1-4.
- [16] Mohammed Abdulazeez, Ires Iskender, "Simulation and Experimental Study of Shading Effect on Series and Parallel Connected Photovoltaic PV Modules", *7th International Conference on Electrical and Electronics Engineering (ELECO)*, 2011, pp. I-28 - I-32.
- [17] Hiren Patel and Vivek Agarwal, "MATLAB-Based Modeling to Study the Effects of Partial Shading on PV Array Characteristics", *IEEE*

*Transactions on Energy Conversion*, VOL. 23, NO. 1, 2008, pp. 302-310.

- [18] Hak-Gyun Jeong, Jae-Sub Ko, Jin-Gook Lee, Da-Eun Jeong, Dae-Kyong Kim, Dong-Hwa Chung, "Development of Active Module Considering the Shadow Influence of Photovoltaic System", *IEEE Vehicle Power and Propulsion Conference 2012*, Seoul, Korea, pp. 1362-1365.
- [19] Kim, K.A. ; Krein, P.T., Photovoltaic Hot Spot Analysis For Cells With Various Reverse-Bias Characteristics Through Electrical And Thermal Simulation, *IEEE 14th Workshop on Control and Modeling for Power Electronics (COMPEL)*, 2013, pp. 1-8.
- [20] Prasenjit Basak, S. Chowdhury, and S.P. Chowdhury, " Simscape Based Modeling and Simulation Of a PV Generator in Microgrid Scenario", *22nd International Conference on Electricity Distribution*, 2013,
- [21] Bhatnagar, P. , Nema, R.K., Control Techniques Analysis of DC-DC Converter For Photovoltaic Application Using SIMSCAPE, *IEEE 5th India International Conference on Power Electronics (IICPE)*, 2012, pp. 1-6.
- [22] Zhun Fan<sup>a\*</sup>, Kisung Seo<sup>a</sup>, Jianjun Hu<sup>a</sup>, Erik D. Goodman, A Novel Evolutionary Engineering Design Approach for Mixed-Domain Systems, *Engineering Optimization*, Vol 36, Issue 2, 2004, pp. 127-147.