International Journal for Modern Trends in Science and Technology
Volume: 03, Issue No: 08, August 2017
ISSN: 2455-3778
http://www.ijmtst.com

SIMSCAPE Model of Solar PV Cell with Partial Shading Effect

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To Cite this Article
B. Sujatha, Renukadevi Chalumuri and K.Baby Lakshmi, “SIMSCAPE Model of Solar PV Cell with Partial Shading Effect”, *International Journal for Modern Trends in Science and Technology*, Vol. 03, Issue 08, August 2017, pp.-92-96.

ABSTRACT

This paper presents the simulation model of PV-cell in MATLAB/Simscape and with pratical experimentation. The study of photovoltaic systems requires an accurate knowledge of the I-V and P-V curves of photovoltaic modules. Performance of PV module/array is analyzed with MATLAB simulation results and the behaviour of IV and Power curves were plotted with experimental results. These graphs shows the effect of irradiance on the output power of solar panel. As the irradiance decreased, the output power is decreased. Due to partial shading on PV cell, the output power is decreased a lot as compared to no shading effect. Using Simelectronics (MATLAB /Simulink) a Simulation model of seventy two solar cells connected in series has been developed. A solar cell block which is available in Simelectronics is used with many other interface blocks to plot I-V and P-V characteristics considering one variation parameter as irradiance.

Keywords: *P-V, I-V Curves, Modeling, Simulation, MATLAB/Simulink Simscape, SimElectronics, Partial Shading Effect*

I. INTRODUCTION

Solar system energy is the most important renewable and sustainable energy system. It has grown consistently and become a popular resource of energy. Solar energy has several applications: photovoltaic (PV) cells are placed on the roof top of houses or commercial buildings, and collectors such as mirrors or parabolic dishes that can move and track the sun throughout the day are also used. This mechanism is being used for concentrated lighting in buildings. Typical applications of solar energy are supply to the residential loads and far off electrical installations. It also has a major role in distributed generation network. Presently solar cell efficiency is relatively low around 12 to 20 %, it means that PV panel can harvest a little amount of sunlight energy (a prototype solar panel with 33.9% efficiency is announced recently by Siemens and North Carolina’s Semprius Inc). Therefore, to preserve this little harvested energy, the whole system such as energy conversion stage has to be designed carefully and efficiently. It enforces system integrator to design very high efficient DC/DC and DC/AC converters. The PV module/array mainly depends on solar irradiation and other environment factors.

Design and Simulation of the PV integrated system requires a precise power electronic circuit model. In this paper, the design of PV system using simple circuit model with detailed circuit modeling of PV module using SimElectronics and the physical equations governing the PV module is presented.

II. SOLAR CELL

PV cell modelling is the very important component that affects the accuracy of the simulation. Modelling of PV cell involves the estimation of the I-V and P-V characteristics curves to assess the real cell under various environmental conditions. The most popular approach is to utilize the electrical equivalent circuit, which is primarily based on diode. The Solar Cell block in SimElectronics, represents a single solar cell as a parallel current source(Iph), an exponential diode(D) and a shunt resistance(Rsh) that are connected in series with a resistance(Rs). Fig.1 shows the symbol of solar cell in SimElectronics.

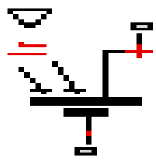

Fig1: Simscape symbol of a Solar cell

In solar cell light energy is converted into electricity (DC) using the photovoltaic effect. The process of conversion first requires a material which absorbs the solar energy (photon) and then raises an electron to a higher energy state and then the flows this high-energy electron to an external circuit. Silicon is one such material that uses such process.

III. CONSTRUCTION OF SOLAR CELL

PV / Solar cells are framed in series and in parallel to form a PV / Solar Panel (Module). The number of series cells indicates the voltage of the Panel (Module), whereas the number of parallel cells indicates the current. PV Array is a combination PV modules in series and parallel. If many cells are connected in series, shading of individual cells can lead to the destruction of the shaded cell otherwise the Panel (Module) may blister and burst. To overcome abnormal conditions, Bypass Diodes are connected anti-parallel to the solar cells. So larger voltage differences cannot arise in the reverse-current direction of the solar cells. To protect from breakage and from the atmospheric conditions a transparent front sheet and backing sheet is fitted.

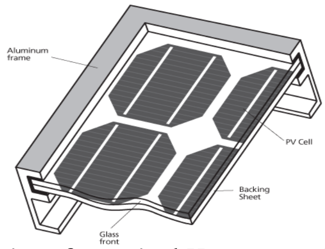

Fig 2: Construction of a typical Mono-crystalline PV / Solar Panel

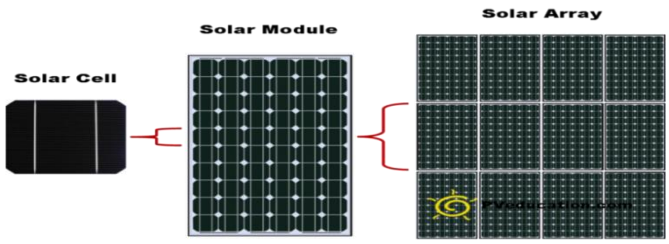

Fig 3: Difference between solar cell, module and array

III. MODELING OF PV MODULE

Modelling of PV modules or arrays is required in order to design and monitor the systems. Usually, a Grey Model process is used to model PV arrays. In such models, physical parameters are determined using the measured data given in the datasheets (by manufacturers).The PV devices are basically represented in two different models viz. Single diode model and Double diode model. An ideal solar cell is modelled by a current source in parallel with a diode. However no solar cell is ideal and there by shunt and series resistances are added to the model as shown in the Fig 4.

V. SINGLE DIODE MODEL OF SOLAR CELL

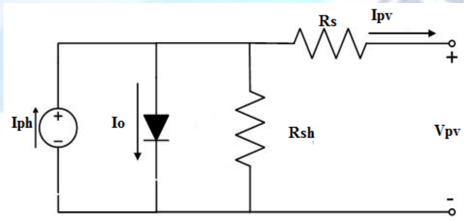

Fig 4 :Single diode Circuit of PV Cell

Ipv represents the cell photo current, Rsh and Rs are the intrinsic series and shunt resistance of the cell respectively. Generally the value of Rsh is very large and that of Rs is very small, hence they may be neglected to simplify the analysis. The model shows less but to solve the equation, single diode model is preferred.

VI. MATHEMATICAL ANALYSIS

O/p PV Module = V_{pv} (V)
O/p Current PV Module = I_{pv} (A)
Reference Temperature T_r = 298 K
Module Operating Temperature = T (K)
Light Generated Current of PV Module = I_{ph} (A)
PV Module Saturation Current = I_o(A)
A = B is an Ideality Factor
k is Boltzman Constant
q is Electron charge
Series Resistance of a PV module = R_s
PV Module Short-Circuit Current at 25⁰C and 1000W/m² = I_{SCr}
Short-Circuit Current Temperature Co-efficient at I_{SCr} = K_i
PV Module Illumination (W/m²) =λ =1000W/m²
Band gap for silicon = E_{go}
No. of cells connected in series = N_s
No. of cells connected in parallel. = N_p
The conversion of operating temperature into centigrade- Kelvin is done by using following equation:
T_{RK} = 273 + 259 (Ref Temp)
T_{ak} = 273 + T_{op}
Module photo-current:
I_{ph} = [I_{SCr}+ K_i (T – 298)] * λ / 1000
Module reverse saturation current Irs :

$$I_{rs} = \frac{I_{sc\,r}}{\left[\exp\left(\frac{QV_{oc}}{N_s kAT}\right)-1\right]}$$

The module saturation current I_0 varies with cell temp:

$$I_0 = I_{rs}\left[\frac{T}{T_r}\right]^3 \exp\left[\frac{q * E_{go}}{Bk}\left\{\frac{1}{T_r}-\frac{1}{T}\right\}\right]$$

Module photo current:

$$I_{ph} = [I_{SCr} + K_i(T-298)] * \lambda/1000$$

Module Reverse saturation current:

$$I_{rs} = I_{SCr}/[\exp(qV_{OC}/N_s kAT)-1]$$

The current output of PV module is:

$$I_{PV} = N_P * I_{ph} - N_P * I_0\left[\exp\left\{\frac{q*(V_{PV}+I_{PV}R_S)}{N_S AkT}\right\}-1\right]$$

VII. SIMELECTRONICS

SimElectronics software works with Simscape Toolbox and adds the physical modelling capabilities for electromechanical and electronic systems. SimElectronics is part of the Simulink Physical Modelling family. Models using SimElectronics are essentially Simscape block diagrams. To build a system-level model with electrical blocks, a combination of SimElectronics blocks and other Simscape and Simulink blocks can be used.

VIII. DIFFERENCE BETWEEN SIMULINK AND SIMSCAPE

Modelling language used to present mathematical models of physical components. The model can be build in Simulink. In brief simulink is a traditional language which converts the modelling equations into block diagram representation. Where as Simscape is a physical by assembling building blocks together to build a complete system with the ability to have different domains.
The main difference is Simscape blocks consist of functional elements that interact with each other by exchanging energy through their bidirectional connection ports. This means that the behaviour of every port will be handled automatically as long as the energy conservation principle is preserved. 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 the article when it comes to study by the behaviour of the shaded solar cell. It will be noticed that the cell current can take two directions, either generated out the cell condition. It is difficult 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. It is not possible to overlap or connect their blocks directly. As a result, transitional structure must be used for this purpose 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. For coupling the simpower systems and Simscape interface blocks are used..

IX. SIMSCAPE MODEL OF SEVENTY TWO CELLS

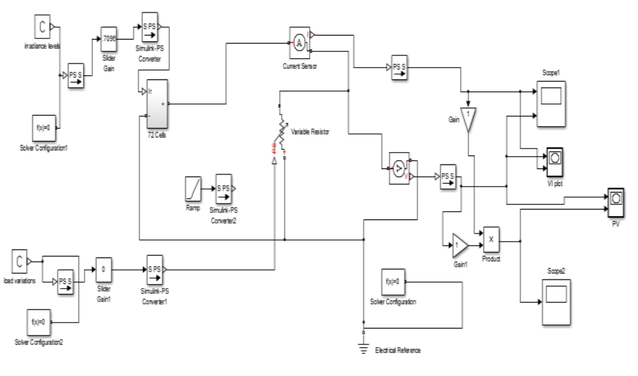

Fig 5: SimElectronics Simulation Model for seventy two Cells

X. SIMSCAPE MODEL OF SIX CELLS

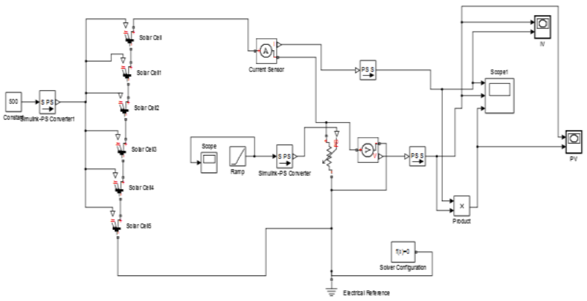

Fig 6:SimElectronics Simulation Model for six Cells

XI. SIMULATION RESULTS OF SOLAR CELLS

Table 1. Simulation values at different Irradiance

Irradiance	V(V)	I(A)	P(W)	Load
50	10	4.8	25	1
100	10	9.8	100	10
150	15	14.75	210	100
200	20	19.7	400	1.00E+16

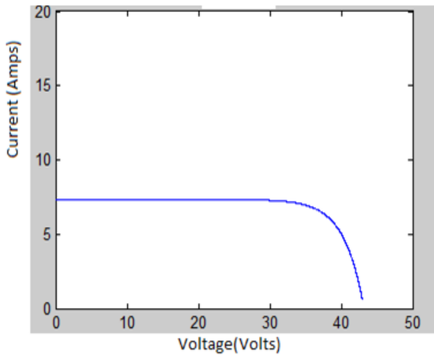

Fig 7:V-I characteristics of PV array

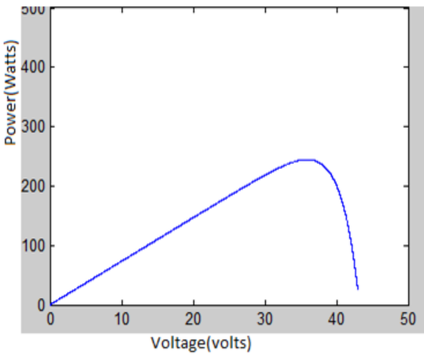

Fig8:P-V characteristics of the PV array

The graph of P-V and I-V are shown. These graphs shows the effect of irradiance on the output power of solar panel. As the irradiance decreased, the power is also decreased. It shows that due to partial shading on PV cell, the output power is decreased a lot as compared to no shading effect.

XII. PARTIAL SHADING EFFECT

When Solar panels are under shaded, they produce less power. In ideal there will never be any shadows on them. But in practical it cannot be avoided, and the effects of partial shading should be considered. Partial shading effect can be demonstrated with the help of developed model in this paper. Partial effect means that solar cell is not getting irradiance or very less irradiance compared to other cells connected in series. Here we connect six cells in series. Five solar cells are given 1000 W/m^2 irradiance and one is given 200 W/m^2 irradiance. This shows that one cell is getting less irradiance, so it decreases whole panel power output to a great extent.

XIII. EXPERIMENTAL SETUP

Fig9: Solar Panels Exposed to Sunlight

Fig 10: One solar panel under partial shading effect

XIV.EXPERIMENTAL VALUES OF SOLARPANEL

Table 2. V, I and P values during different timings

Temp	V(V)	I(A)	P(W)	Time
33	20	1	5	11:00AM
33	20	0.9	4	11:15AM
33	19	0.7	3.4	11:30AM
34	19	0.55	2.2	11:45AM
35	18	0.37	1.3	12:00PM
35	18	0.2	0	12:15PM
36	18	0.1	0	12:30PM

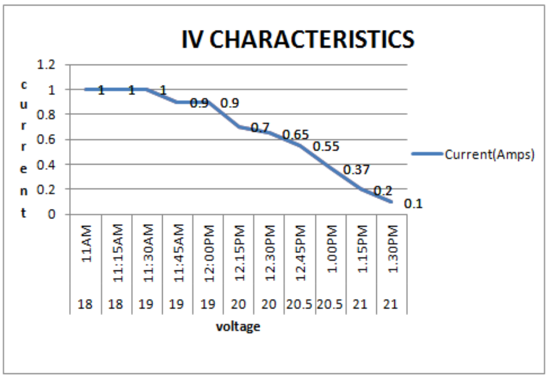

Fig 10:I-V plot for experimental values

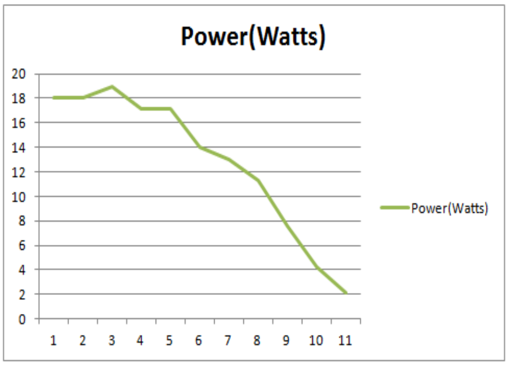

Fig11:Power plot for experimental values

XV. CONCLUSION

Simulation model of a solar cell has been developed in Simelectronics (MATLAB/Simulink) using solar cell block and other interfacing blocks. The objective of these models is to achieve similar I-V and P-V characteristics curves to the graphs which are in the datasheet of the manufacturer of the different solar panels. The most similar will be the best model, or the one that resembles like the physical model. In low sun irradiation level, two-diode model is more accurate. The solar irradiation pattern is low irradiation in the morning and in the evening obviously two diode model will be the best choice and is very close to real situation. Simscape based models have its intrinsic advantages that researcher has variety of built in tools for further study. Here PV model is able to integrate by abundant built-in power system components available in the software library. Partial shading effect can be minimized by locating the solar panel array where there will be no regular shading , using micro inverters in place of normal string inverters and using inverter which has Maximum power point tracking capability.

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