

# Simplified Modeling of a PV Panel by using PSIM and its Comparison with Laboratory Test Results

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**Abstract**— This paper presents an easy and accurate procedure of the modeling of a commercially available Photovoltaic Panel by using Solar Module (Physical Model) Simulator embedded in a very powerful Simulation software known as PSIM. Methods of Photovoltaic Panel modeling including mathematical modeling and software based modeling are also discussed in this paper. Apart from modeling types, I-V (Current-Voltage) and P-V (Power-Voltage) Characteristics and some other useful results obtained from PSIM Simulation are further evaluated and compared with the laboratory test results. Limitations of PSIM Solar Module (Physical Model) are also discussed in this paper.

**Keywords**—Photovoltaic Panel, Modeling Methods, PSIM modeling, Laboratory Testing.

## I. INTRODUCTION

Renewable Energy development has been an increasingly demanding topic in the 21st century due to global warming and several kinds of environmental factors. The growth rate of renewables is very fast. For Electric Power Generation, various alternative renewable energy sources are very popular these days. These alternative sources are geothermal, wind, water and solar etc.

Photovoltaic (PV) devices or PV Panel terminology is certainly nothing new; their use has become more common, practical and effective for people worldwide [1]. The main reason why PV Panels are gaining popularity in the field of electric power generation is due to the fact that they do not emit greenhouse gases, they do not have any rotating part, their life time is very long and during usage they require less maintenance [1]. Output Power of a Photovoltaic Panel is not always constant; it varies all the time due to environmental changes. So, in order to operate PV Power System at its maximum level of efficiency, it is necessary to force the system to operate at maximum power point (MPP) of that PV Module which can be identified on current-voltage (I-V) and Power- Voltage (P-V) performance characteristics of that Module as shown in Fig 1.

In this paper, authors give an overview of the PSIM Simulator with the help of which performance characteristics and maximum power point of a PV Panel can be identified. These

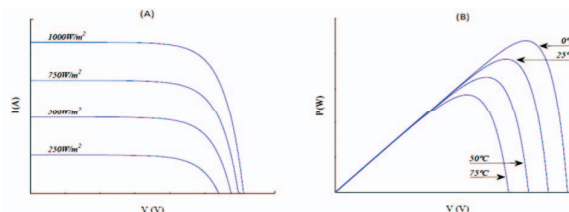


Fig.1 (A) Current-Voltage characteristic of PV module for different irradiances (B) Power-Voltage characteristics of photovoltaic module for different temperatures.

are the most important things in order to design Power Electronic (PE) Converter. Apart from that comparison of results and limitations of PSIM are also reviewed.

## II. MODELING OF PV PANEL

Photovoltaic Panel is made up of a number of cells and each of them behaves in a different way under changing environmental conditions which ultimately varies maximum power point (MPP) of that panel [2]. Under these conditions it is very tedious job to design a Power Electronic (PE) converter, Maximum Power Point Tracking (MPPT) and control strategy for that PV Panel [3]. In order to extract important characteristics of a PV Panel i.e. I-V and P-V Characteristics and maximum power point, one need to model that PV Panel accurately to predict its behavior under various operating and environmental conditions.

## III. METHODS OF MODELING

In literature, several methods have been developed to model a PV Panel. The basic two methods that are presently use in industry are as follows:

- 1.) Mathematical Modeling
- 2.) Software/Simulation Based Modeling

### 1.) Mathematical Modeling

To simulate the behaviour of a PV Panel, mathematical modeling can be used. In this kind of modeling technique an

equivalent circuit of PV Cell can be represented by a current source which is parallel with diode. Two resistances  $R_s$  (Series Resistance) and  $R_{sh}$  (Shunt Resistance) are also included in it [4], as shown in Fig 2. The value of these resistances can be found either by using measurement method or by curve fitting (approximation) method [4].

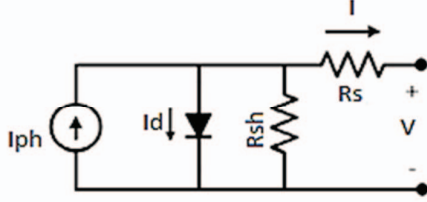


Fig.2 Equivalent and Simplified Model of PV Cell

In order to derive basic characteristics (I-V & P-V) of PV Panel by using mathematical method of modeling, there is a need to understand some basic equations which are as follows [4],[5]:

Input Power ( $P_{in}$ ):

$$P_{in} = V_d \cdot I_{ph} \quad (1)$$

Diode Current ( $I_d$ ):

$$I_d = I_{sat} \left[ e^{\frac{V}{V_t}} - 1 \right] \quad (2)$$

Output Current (I):

$$I = I_{ph} - I_d - \frac{R_s I + V}{R_{sh}} \quad (3)$$

Open Circuit Voltage ( $V_{oc}$ ):

$$V_{oc} = V = \frac{nkT}{q} \ln \left[ \frac{I_{ph}}{I_d} + 1 \right] \quad (4)$$

Short Circuit Current ( $I_{sc}$ ):

$$I_{sc} = I_{ph} (V = 0) \quad (5)$$

Where,

$I_{ph}$  =Light-generated photo-current of PV model

$I_{sat}$ = Diode saturation Current

$V_t$  = Thermal voltage of the solar cell

$n$  = Diode ideality factor,  $k$  = Boltzmann's constant

$T$ = operating temperature,  $q$ = Charge of an electron

Now usually in mathematical approach of modeling,  $R_s$  and  $R_{sh}$  are unknown. However, these two parasitic resistances are necessary to include in modeling because  $R_s$  is the internal loss due to current flow and  $R_{sh}$  is the loss due to manufacturing defects. Finding these two parasitic resistances values means solving a non-linear equation as given in [4]. Some of the techniques to solve non-linear equations are Newton-Rapshon, curve fitting etc [5]. Therefore, with software modeling, there is no need to solve these non-linear equations and apart from that software modeling is also more accurate and less time consuming because it also avoids the need of curve fitting and other trial and error methods used in mathematical modeling.

## 2.) Software/Simulation Based Modeling

To derive ideal performance characteristics (I-V & P-V) of a PV Panel, software based simulation can be considered more suitable tool because of its more accuracy and precision where the chances of error are also very less. Apart from these advantages, for the modeling purpose of solar panel, software based simulation often requires less parameter from solar panel's datasheet. Several software and simulators are available in market such as: PSIM, MATLAB/Simulink etc... Every simulator requires some basic parameters of a PV Panel which are available in its data sheet.

In this paper, Solar Module (Physical Model) Simulator is used for simulation that is readily available in a specialized Power simulator called PSIM [6]. This model is also based on equivalent circuit of PV Panel.

## IV. PSIM AND ITS SOLAR MODULE

The physical model of Solar Panel is available in the utility menu of PSIM software as shown in Fig 4. This model requires basic parameters of Solar Panel, some of them can be obtained from data available on back side of PV Panel and some of them can be obtained from environmental factors e.g temperature. Although this simulator also requires data sheet parameters but still there is a space of finding other parameters of PV Panel just like in the case of shunt resistance ( $R_{sh}$ ) which you provide randomly to PSIM and then PSIM automatically calculate series resistance ( $R_s$ ). This model also takes into account variation of light irradiance level and ambient temperature [6]. The basic parameters required for simulation are listed below:

- Maximum Power ( $P_{max}$ )
- Voltage at  $P_{max}$  ( $V_{mp}$ )
- Current at  $P_{max}$  ( $I_{mp}$ )
- Short Circuit Current ( $I_{sc}$ )
- Open Circuit Voltage ( $V_{oc}$ )
- Light Intensity ( $S_0$ )
- Temperature ( $T_{ref}$ )

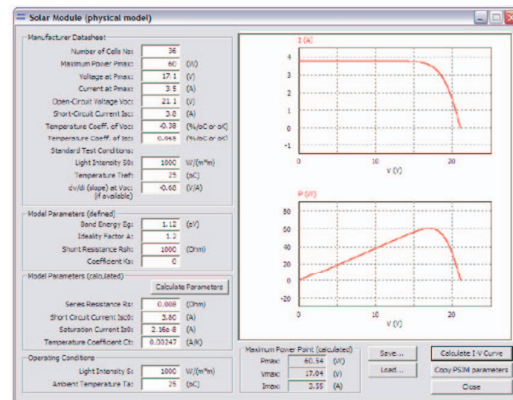


Fig.4 Solar Module (Physical Model) Simulator in (PSIM)



## VIII. LABORATORY TEST RESULTS

In order to find performance characteristics under laboratory arrangement at different irradiance levels, just vary the distance between PV Panel and Light Source as well as the value of variable resistance while rest of the arrangement remains same.

Similar to simulation results, laboratory based performance characteristics have also been taken at four different irradiance levels which are 439.4 W/m<sup>2</sup>, 325.6 W/m<sup>2</sup>, 291.4 W/m<sup>2</sup> and 141.6 W/m<sup>2</sup>.

Irradiance at 141 W/m <sup>2</sup>			
Resistance	Current	Voltage	Power
0	0.088	0.02	0.00176
13	0.088	1.15	0.1012
17.2	0.088	1.53	0.13464
25.25	0.088	2.28	0.20064
50.7	0.088	4.53	0.39864
66	0.087	5.58	0.48546
98	0.086	8.65	0.7439
132	0.085	11.3	0.9605
164.8	0.083	13.8	1.1454
198	0.077	15.35	1.18195
240	0.065	16.33	1.06145
10000000	0	19.83	0

Irradiance at 291.4 W/m <sup>2</sup>			
Resistance	Current	Voltage	Power
0	0.15	0.05	0.0075
13	0.147	2.07	0.30429
17.2	0.1464	2.73	0.399672
25.25	0.1448	3.86	0.558928
50.7	0.1375	7.2	0.99
66	0.1326	9	1.1934
98	0.1264	12.8	1.61792
132	0.1138	15.3	1.74114
164.8	0.0985	16.5	1.62525
198	0.0862	17.4	1.49988
10000000	0	20.8	0

Irradiance at 325.6 W/m <sup>2</sup>			
Resistance	Current	Voltage	Power
0	0.188	0.08	0.01504
13	0.187	2.46	0.46002
17.2	0.186	3.23	0.60078
25.25	0.183	4.71	0.86193
50.7	0.175	9	1.575
66	0.168	11.32	1.90176
98	0.158	15.92	2.51536
132	0.135	18.06	2.4381
164.8	0.114	19.1	2.1774
198	0.098	19.7	1.9306
10000000	0	20.5	0

Irradiance at 439.4 W/m <sup>2</sup>			
Resistance	Current	Voltage	Power
0	0.192	0.024	0.004608
13	0.1895	2.67	0.505965
17.2	0.1884	3.45	0.64998
25.25	0.1868	4.98	0.930264
50.7	0.1828	9.54	1.743912
66	0.1785	12.14	2.16699
98	0.1606	16.29	2.616174
132	0.1344	18	2.4192
164.8	0.113	18.9	2.1357
198	0.096	19.2	1.8432
10000000	0	20	0

Table 1. Shows the readings of Voltage (V), Current (I) and Power (P) taken by varying variable (load) resistor at four different average irradiance levels mentioned above

### Performance Characteristics:

After getting V,I & P values from above mentioned results. One can easily plot I-V and P-V Performance characteristics by using a specialized graph plotting software such as MS Excel or Matlab. In this paper, MS Excel has been used to plot I-V and P-V performance characteristics as shown in Fig 8.

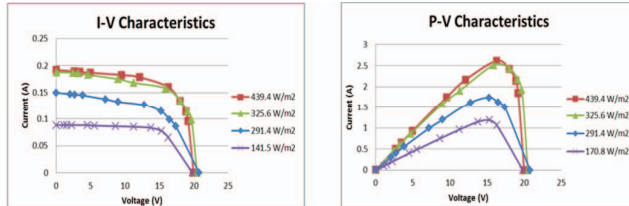


Fig 8. Laboratory Testing based V-I and P-V Performance Characteristics of given PV Panel

## IX. COMPARISON OF RESULTS

Comparison of Model based and experiment based performance characteristics of a given PV Module gives the following outcomes:

- Open circuit voltages are almost similar in both modeled and experimental cases due to less temperature variations. But in both cases, value of Voc is slightly different from specified open circuit voltage (Voc).
- Short circuit current have an observable variations in both cases. In testing case, due to availability of non-ideal replica of sunlight (metal halide lamp), PV Panel could not have enough exposure of light radiations in order to produce required short circuit current.
- Due to the variation in short circuit current, the slope of tested performance characteristics are not same and this ultimately gives a different maximum power point for each irradiance level as compared to the modeled one. In both modeled and experimental cases, irradiance level of 439.4 W/m<sup>2</sup> gives more stable and maximum power which is equal to 2.6 W (Tested) and 4.76 W (Modeled).
- By using equations of efficiency and fill factor, one can easily find fill factor and efficiency of a given Solar Panel. Due to more stable performance characteristics available at irradiance level of 439.4 W/m<sup>2</sup>, The detailed comparison of its modeled and tested fill factor and efficiency is as follows:

### Modeled Results:

$$\text{Fill Factor (FF)} = \frac{V_{mpp} \cdot I_{mpp}}{V_{oc} \cdot I_{sc}} = \frac{17 \cdot 0.28}{0.3 \cdot 20} = 0.78$$

$$\text{Efficiency (n)} = \frac{V_{oc} \cdot I_{sc} \cdot FF}{P_L} = \frac{20 \cdot 0.3 \cdot 0.78}{439 \cdot 0.0639} \cdot 100 = 16.39\%$$

### Tested Results:

$$\text{Fill Factor (FF)} = \frac{V_{mpp} \cdot I_{mpp}}{V_{oc} \cdot I_{sc}} = \frac{16.29 \cdot 0.16}{0.192 \cdot 20} = 0.62$$

$$\text{Efficiency (n)} = \frac{V_{oc} \cdot I_{sc} \cdot FF}{P_L} = \frac{20 \cdot 0.192 \cdot 0.66}{439 \cdot 0.0639} \cdot 100 = 9.93\%$$

	Irradiance Level =325.6 W/m <sup>2</sup>		Irradiance Level =291.4 W/m <sup>2</sup>		Irradiance Level =141.5 W/m <sup>2</sup>	
	Modeled	Tested	Modeled	Tested	Modeled	Tested
Fill Factor	0.72	0.65	0.77	0.558	0.76	0.67
Efficiency	14.53%	12.04%	14.9%	9.3%	14.5%	12.9%

Table 2. Modeled/Tested Fill Factor & Efficiency at irradiance levels of 325.6, 291.4 and 141.5 W/m<sup>2</sup>

- By observing the above given data, it can easily be seen that the efficiency and fill factor of ideal case is slightly



greater than the actual one specially at lower irradiance level (325.6, 291.4 and 141.5 W/m<sup>2</sup>) but higher radiation like 439.4 W/m<sup>2</sup> could not follow this trend and give more difference between ideal and actual values which again shows that ideal performance characteristics are more accurate.

- The main reason of this uneven behavior is due to the absence of light radiations on whole PV Panel's surface at 439.4 W/m<sup>2</sup>. In this case, light source only cover a very limited area and that is why it gives high current but less fill factor which furthermore reduces efficiency. As far as lower radiations are concerned they have high efficiency and fill factor but as their distance from light source is larger, they produce less current which ultimately gives lower MPP Point as compared to higher irradiance level (439.4 W/m<sup>2</sup>).

## X. LIMITATIONS OF PSIM

Solar Module (Physical Model) of PSIM works perfectly in order to plot I-V and P-V characteristics of a commercially available PV Panel but PSIM also have some limitations. First limitation is the unavailability of the modeling of a material specific photovoltaic panel. This PSIM Solar Module can be further improved if the developer adds some option of PV Panel's material specifications. Apart from this limitation, another most important limitation is the non-compatibility of Solar Module (Physical Model) of PSIM with other simulation software's e.g. MATLAB. If developer also makes PSIM more compatible with other Simulation software's then PSIM usage can be improved.

## XI. CONCLUSION

This paper presented a simple and accurate modeling method of a commercially available photovoltaic panel using PSIM software. First, authors discussed the existing modeling methods of photovoltaic panels (mathematical and simulation software). Later, the methodology related to PSIM simulation and then laboratory testing of a photovoltaic panel has been described. The modeling of this commercially available PV panel is based on specifications given on the manufacturer's plate. Laboratory testing allowed authors to test the accuracy of performance characteristics and getting real data under different arrangements. Moreover, comparison of the simulation results with the laboratory results has also done in order to register the observations regarding the similarities and gaps in performance between the two of them. In conclusion, by using PSIM, modeling of PV Panel can be done very accurately but still this software has some limitations, if developer adds these aspects in PSIM then it could be used more effectively.

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## References

- [1] Farooq, M.; Salman. A.; Siddique, A, S.; Khalil, I, M.; Mukhtar, W. "Economically Designed Solar Car for Developing Countries (Pakistan)", Global Humanitarian Technology Conference (GHTC), 2014 IEEE, San Jose, CA, USA.
- [2] HILL, M. D. A. A. R. (2001). Clean Electricity from Photovoltaics, UK, Imperial College Press.
- [3] RASHID, M. H. (2001). Power Electronics Handbook, Butterworth-Heinemann.
- [4] Francisco M. González-Longat (2005), "Model of Photovoltaic Module in Matlab", 2do congreso iberoamericano de estudiantes de ingeniería eléctrica, electrónica y computación, (II CIBELEC 2005).
- [5] Marcelo Gradella Villalva, Jonas Rafael Gazoli, and Ernesto Ruppert Filho (2009), "Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays," IEEE Transactions on Power Electronics, Vol. 24, no. 5, May 2009.
- [6] INC., P. S. Tutorial on How to Use Solar Module Physical Model [Online]. Power Sim Inc. Available: [http://www.psim-europe.com/openload2.php?doc=Tutorial-Solar\\_Module\(physical\\_model\).pdf](http://www.psim-europe.com/openload2.php?doc=Tutorial-Solar_Module(physical_model).pdf).