



Modeling of Solar Photovoltaic Module and Effect of Variation of Insolation Using Matlab/Simulink

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ABSTRACT: The photovoltaic module is developed with step-by-step procedure for the simulation of photovoltaic modules with MATLAB/SIMULINK. The model is developed using basic circuit equations of the Photovoltaic (P-V) cells including the effects of solar radiation and temperature changes. Since the P-V module has nonlinear characteristics, and the Photovoltaic system characteristic curves as current-voltage (I-V) and power-voltage (P-V) characteristics are drawn according to values change of the temperature and solar radiation which is observed in MATLAB-SIMULINK. For this One-diode equivalent circuit is employed in order to investigate I-V and P-V characteristics of a typical 36W solar module and draws according to values changes of the temperature and solar irradiation which is observed in MATLAB-SIMULINK environment also the simulation time taken is more because it obtained better results or it calculates more accurate point to point calculation. Here only two cases are taken with this step-by-step procedure and analyze the effect of temperature and irradiance with these two cases. In the first one constant temperature and constant irradiance are taken and then the I-V and P-V characteristics are observed. In the second case varying temperature varying irradiance is taken and I-V, P-V characteristics are observed.

Keywords: Photovoltaic module, power system, Matlab/Simulink.

Nomenclature

V_{pv} is output voltage of a PV module (V)
 I_{pv} is output current of a PV module (A)
 T_r is the reference temperature = 298 K
 T is the module operating temperature in Kelvin
 I_{ph} is the light generated current in a PV module (A)
 I_0 is the PV module saturation current (A)
 $A = B$ is an ideality factor = 1.6
 k is Boltzman constant = 1.3805×10^{-23} J/K q is
Electron charge = 1.6×10^{-19} C
 R_s is the series resistance of a PV module
 I_{SCr} is the PV module short-circuit current at 25°C and
 $1000\text{W/m}^2 = 2.55\text{A}$
 K_i is the short-circuit current temperature co-efficient at
 $I_{SCr} = 0.0017\text{A} / ^\circ\text{C}$
is the PV module illumination (W/m^2) = 1000W/m^2
 E_{go} is the band gap for silicon = 1.1 eV
 N_s is the number of cells connected in series
 N_p is the number of cells connected in parallel

I. INTRODUCTION

In order to diminish the greenhouse effect and slow the depletion of fossil fuel, solar energy systems have been developed [1]. Solar energy is green energy, which is inexhaustible and environmentally friendly. It is becoming one of the most promising alternatives for conventional energy sources. Due to this, photovoltaic solar energy has been increasingly used to generate

electric power from sunshine [2]. Although the rapid development of photovoltaic material technology have reduced the production cost of solar PV (Photovoltaic) modules [3], generating electricity from a solar cell is still considered as an expensive method compared with conventional fossil fuel generated electric power [1]. Solar energy obtained from a solar PV cell is not constant all the time. Solar energy is affected by external conditions like solar irradiance and temperature. Solar irradiance and cell temperature are pointed out to be affecting PV cell output to a much greater extent than the other conditions [4]. Moreover, the amount of extracted power from a PV system is a function of the PV array voltage and current set point. Due to these reasons stated above, it is crucial to maximize the output electric power available from the PV cell. Actually the solar PV cell has nonlinear I-V and P-V characteristics which is depends on the irradiance and the operating temperature also in load condition of the cell [4]. Patel and Agarwal [5] proposed the MATLAB based modeling and study the effects of partial shading on PV array characteristics. PV module characteristics and mathematical modeling are comprehensively discussed in [6-13], which indicate an exponential and nonlinear relation between the output current and voltage of PV module.

The solar energy is a dilute source of energy and its availability varies widely with time.

So, it is very necessary to make a complete utilization of solar energy in available time.

For this purpose an improved PV module has been introduced which is the development of mathematical modeling of PV arrays. The objective is to validate the P-V & I-V characteristics of practical solar PV arrays.

II PRINCIPLE OF OPERATION

PV Cells are basically made up of a PN junction fabricated in a thin wafer or layer of semiconductor (usually the material used is silicon). As the photocurrent generation principle of PV cells. In fact, when sunlight hits on the cell, the photons are absorbed by the semiconductor atoms, freeing electrons from the negative layer. These free electrons find its path towards the positive layer through an external circuit, resulting in An electric current flows from the positive layer to the negative layer. Typically, generated voltage of this PV cell is around 0.5 to 0.8 volts depending on the semiconductor and the built-up technology.

This voltage is low enough as it cannot be of use. Therefore, to get benefit from this technology, many of PV cells (involving 36 to 72 cells) are connected in series to form a PV module. These modules can be interconnected in series and/or parallel to form a PV panel. In case these modules are connected in series, their voltages are added with the same current. Nevertheless, when they are connected in parallel, their currents are added while the voltage is the same the same principle technique is used in this paper and connected a 36 cells in series-parallel connection which generates following.

Specifications

Maximum Power Voltage(V_{max})=22 V
Maximum Power Current (I_{max}) = 3.33A
Module Dimension (LxWxH)(mm)=702X666X34
No. of Solar Cells = 36
Normal Operating Cell Temp(NOCT)=25±2 C

III. MODELLING OF PV CELL

The solar cell is the basic unit of a PV system. Solar Cell or Photovoltaic (PV) cell is a device that is made up of semiconductor materials such as silicon, gallium arsenide and cadmium telluride, etc. that converts sunlight directly into electricity. The voltage of a solar cell does not depend strongly on the solar irradiance but depends primarily on the cell temperature. PV modules can be designed to operate at different voltages by connecting solar cells in series. When solar cells absorb sunlight, free electrons and holes are created at positive/negative junctions. If the positive and negative junctions of solar cell are connected to DC electrical equipment, current is delivered to operate the electrical equipment.

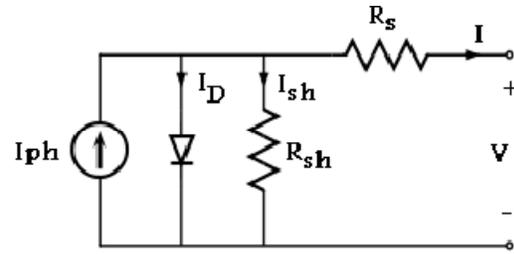


Fig.1. PV cell equivalent circuit.

The P-V cell equivalent circuit as shown in fig1. PV arrays are built up with combined series/parallel combinations of P-V solar cells, which is usually represented by a simplified equivalent circuit model such as given in Fig1. The PV cell output voltage is a function of the photocurrent that mainly determined by load current depending on the solar irradiation level during the operation.

I_{ph} = Photo current, I_D = Diode current V = Output Voltage
 I_{sh} = Shunt current, R_{sh} = Shunt resistor, R_s = Series resistor.

IV. EQUATIONS FOR EQUIVALENT PV CIRCUIT

Module photo-current –

$$I_{ph} \approx [I_{sc} K_t (T - 298)]^* / 1000 \quad (1)$$

Modules reverse saturation current –

$$I_{rs} = I_{scr} / [\exp(qV_{oc}/N_s kAT) - 1] \quad (2)$$

The module saturation current I_0 varies with the cell cell temp which is given by.

$$I_0 = I_{rs} [T/T_r]^3 \exp[q^* E_{go} / BK \{1/T_r - 1/T\}] \quad (3)$$

The current output of PV modulated is

$$I_{pv} = N_p I_{ph} - N_p I_0 [\exp\{q^* (V_{pv} + I_{pv} R_s) / N_s AKT\} - 1]$$

Where

$$V_{pv} = V_{oc}, N_p = 1, N_s = 36$$

V. BASIC FUNCTIONAL MATLAB-SIMULINK MODULE OF THE PHOTOVOLTAIC ARRAY MODEL

The basic model used for solar pv cell is designed in MATLAB-SIMULINK environment as show here. A circuit based simulation model for a PV cell for estimating the I-V characteristic curves of photovoltaic panel with respect to changes on environmental parameters (temperature and irradiance) and cell parameters (parasitic resistance and ideality factor).

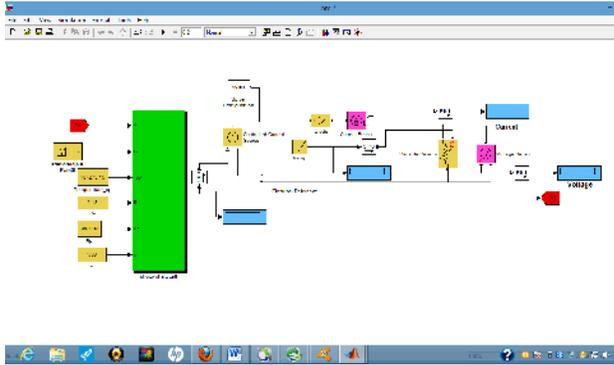


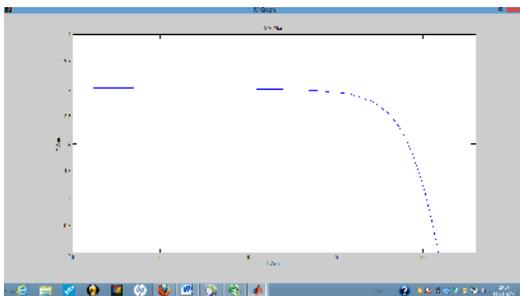
Fig. 2.

This paper could use to analyze in the development of MPPT(maximum power point tracking) algorithm. Using a Stocky diode equation, an accurate Simulink PV panel model is developed.

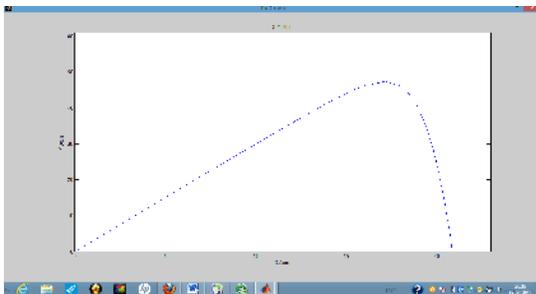
In the above figure.2 shows the basic MATLAB-SIMULINK model which gives the basic idea about PV cell. A model of PV module with moderate complexity that includes the temperature independence of the photocurrent source, the saturation current of the diode, and a series resistance is considered based on the Shockley diode equation.

Being illuminated with radiation of sunlight, PV cell converts part of the photovoltaic potential directly into electricity with both I-V and P-V output characteristics.

I-V Curve



P-V Curve



With the help of above model. An Another model is developed in MATLAB-SIMULINK environment of PV module with constant irradiance and constant temperature of 25°C then I-V and P-V characteristics under constant irradiation with constant temperature are obtained as shown here.

VI. MODEL OF PV MODULE WITH CONSTANT IRRADIATION AND CONSTANT TEMP 25C

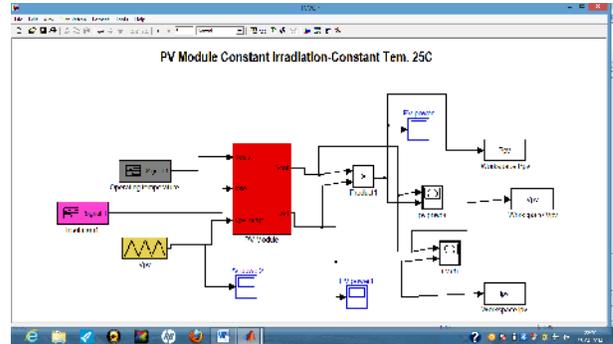
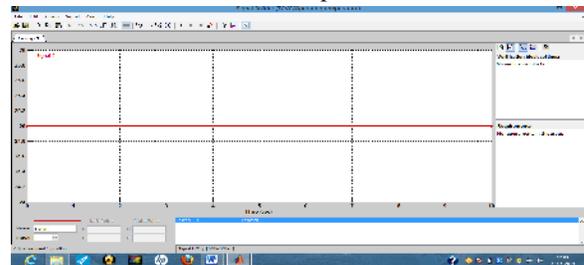


Fig. 3.

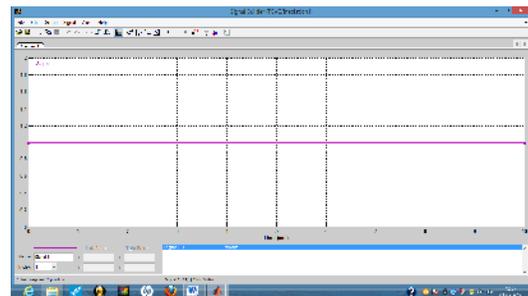
(a) Performance Estimate with the developed model, and PV module characteristic is estimated as follows.

PV Module constant Temperature



This is the signal builder block of PV Module which indicate the input temperature is used. As there is constant temperature is used means it takes normal room temperature 25C and see the effects on P-V, I-V characteristics

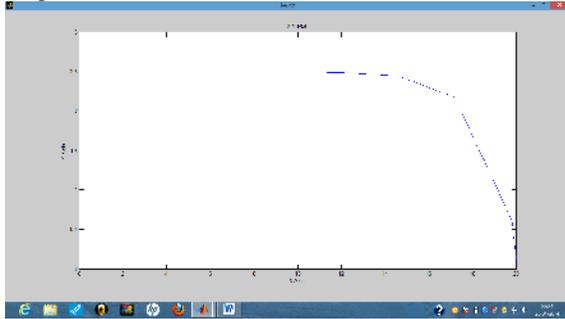
PV Module constant irradiance



This is screen shot of another signal builder block which gives the information about input irradiance used. Here constant irradiance is used and see the effects on P-V, I-V characteristics PV Module.

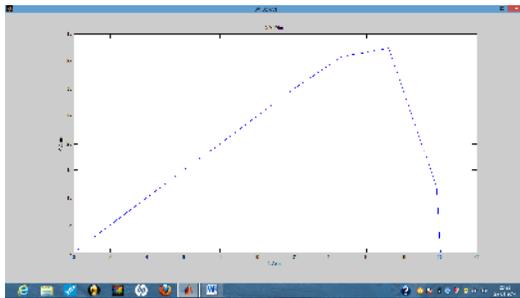
Different curves

I-V Curve under constant irradiance and constant temperature.



From the above model of case.1 as shown in fig.3 with constant temperature and constant irradiance it gives following I-V, P-V curve.

P-V Curve under constant irradiance and constant temperature.



It is observed that in both the graphs sharpness or corners are indicated this is due to with the simulation time is maximum this maximum time is used because of accurate result is obtained.

Table 1.

S. N.	SET: 4	VOLT AGE	CURRENT (mA)	POWER (WATTS)
1	Irradiance: 1000 watt/m ²	1.6	2.5(I _{sc})	4
2		4.2	2.5	10.5
3		6.8	2.5	17
4		9.4	2.499	23.49
5	Temp: 25C	12	2.492	29.91
6		14.6	2.499	35.76
7		17.2	2.175	37.41(P _{max})
8		19.8 (Voc)	0.6108	12.09

From the above P-V, I-V curves following information are gained which indicate in table.1

VII. PV MODULE VARYING IRRADIATION VARYING TEMPERATURE

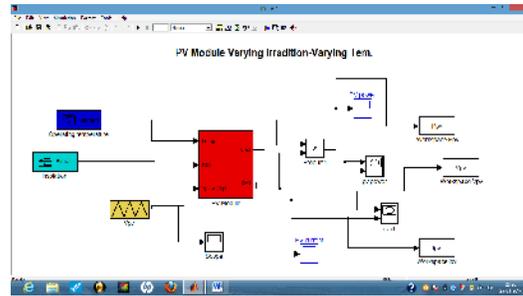
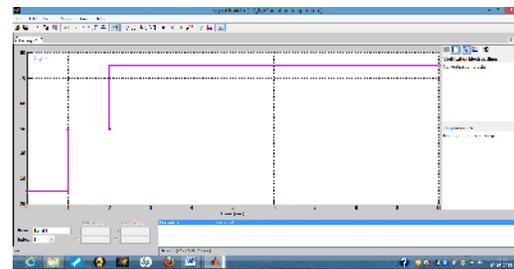


Fig. 4.

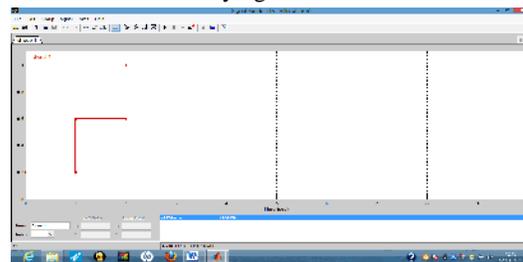
Then another model of PV module is developed in MATLAB-SIMULINK environment as shown in fig.4 with varying irradiation and varying temperature.

PV Module varying temperature



Here indicate the signal builder block of PV module with varying temperature input. The temperature is increased step by step from 25C, 50C and 75C.

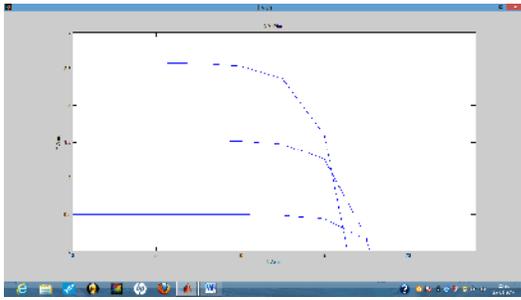
PV module varying irradiance



In this signal builder block input irradiance is increased step by step firstly it is in 0.2 then 0.6 then 1.00 from these varying inputs are given to pv module then I-V, P-V Curves are obtained.

Different curves

(a) I-V Curve under varying irradiance & varying temp.



(b) P-V Curve under varying irradiance and varying temp.

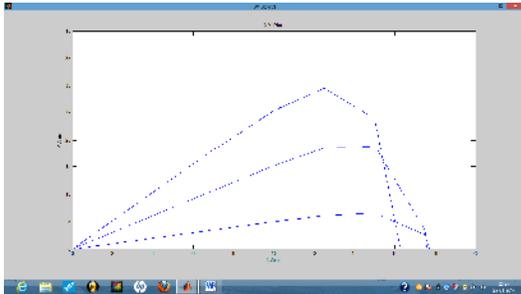


Table.2

S. N.	SET: 2	VOLT AGE	CURREN T (mA)	POWER(WATT S)
1	Irradiance: 200 watt/m ² Temp: 25C	0	0.5(I _{sc})	0
2		5	0.5	2.5
3		10	0.4984	4.984
4		15(V _{oc})	0.4412	6.618(P _{max})
1	Irradiance: 600 watt/m ² Temp: 50C	0	1.525(I _{sc})	0
2		5	1.525	7.626
3		10	1.516	15.16
4		15(V _{oc})	1.255	18.82 (P _{max})
1	Irradiance: 1000 watt/m ² Temp: 75C	0	2.585(I _{sc})	0
2		5	2.583	12.91
3		10	2.537	25.37(P _{max})
4		15(V _{oc})	1.597	23.95

VIII. CONCLUSION

Here the step-by-step procedure is done for modeling of PV module is presented. This mathematical modeling is done with the help of firstly studied basic model of PV module. Then I have to develop some models from which obtained P-V, I-V characteristics. After that it is also tried to make better PV module in comparison to already exist so that it may produce more output voltage making sure that this output voltage is constant and doesn't have any unwanted fluctuations. For this I made many changes to the model. Basically the output were taken in two cases, in the first case I kept irradiance constant and temperature

constant then in second case I varied irradiance as well as temperature varied and obtain different P-V and I-V values so that different curves are obtained. An accurate PV module is presented and demonstrated in MATLAB/SIMULINK and the simulation run timescale is also large here.so that better results could be obtained. It can be observed that the PV current I_{ph} is a function of the solar irradiation and is the only energy conversion process in which light energy is converted to electrical energy.

REFERENCE

[1]. Jenifer.A, Newlin, Nishia.R ,Rohini.Jamuna,V' "Development Of Matlab-Simulink Model For Photovoltaic Arrays " pp. 436447[ICCEET] 2012.
 [2]. Savita Nema, R.K. Nema, Gayatri Agnihotri, "MATLAB/Simulink based study of photovoltaic cells/ modules/array and their experimental verification", *International journal of Energy and Environment*, vol.1, No.3, pp.487-500, 2010.
 [3]. I.H. Atlas, A.M. Sharaf, "A Photovoltaic Array Simulation Model for Matlab-Simulink GUI Environment", *International Conference on Clean Power*, pp. 341-345, 2007.
 [4]. Francisco M,González-Longatt, "Model of Photovoltaic Module in Matlab™",To do congresos beroameri canodee studiantes de ingenieríaeléct ca, electrónica y computación pp.1-5, 2005
 [5]. D.Popni,"Analysis of diffusion paths for photovoltaic technology based on experience curves", *Solar Energy*, Vo.64, pp. 331-340,2003.
 [6]. "Hiren Patel and Vivek Agarwal" MATLAB-Based Modeling to Study the Effects of Partial Shading on PV Array, *IEEE transactions on energy conversion*, vol. 23, no.1,pp 302-310 march 2008
 [7]. D.zung, D.Nguyen, and Brad Lehman, "Modeling and Simulation of Solar PV Arrays under Changing Illumination Conditions", *IEEE COMPEL Workshop, Rensselaer Polytechnic Institute, Troy, NY, USA*, July 16-19, 2006
 [8]. Y-C.Kuo, T-J.Liang, and J-F.Chen. "Novel Maximum-Power-Point- Tracking Controller for Photovoltaic Energy Conversion System", *IEEE Transactions On Industrial Electronics*, Vol. 48, No. 3, pp.594-601, June 2001
 [9]. M.A.S. Masoum, H. Dehbonei, and E. F. Fuchs. "Theoretical and Experimental Analyses of Photovoltaic Systems with Voltage-and Current-Based Maximum Power-Point Tracking", *IEEE Transactions on Energy Conversion*, Vol. 17, No. 4, December 2002, pp.514-522.
 [10]. L.Fangrui, Y. Kang, Y. Zhang, and S. Duan. "Comparison of P&O and Hill Climbing MPPT Methods for Grid-Connected PV Converter, "Industrial Electronics and Applications, 3rd IEEE Conference on. pp. 804-7. 2008.
 [11]. Matlab and Simulink, "The Mathworks, Inc. <http://www.mathworks.com>.
 [12]. www.bpsolar.com. BP SX150 Datasheet

- [13]. Vaigundamoorthi M, and Ramesh R “ZVS-PWM active-clamping modified Cuk converter based MPPT for solar PV modules”, *European Journal of Scientific Research*, Vol **58**, No. 3, 305–315,2011.
- [14]. Walker. G “Evaluating MPPT converter topologies using a MATLAB PV modul”, *Journal of Electrical and Electronics Engineering, Australia*, vol **21**(1), pp49–56,2001.
- [15]. Safari A, and Mekhilef S. “Simulation and hard- ware implementation of incremental conductance MPPT with direct control method using Cuk converter”, *IEEE Transactions on Industrial Electronics*, vol. **58**(4), pp1154–1161, 2011.
- [17]. Villalva MG, Gazoli JR. “Comprehensive approach to modeling and simulation of photovoltaic array”, *IEEE Transactions on Power Electronics*, vol. **24**(5), pp1198–1208. (2009).