ISSN (e): 2250 – 3005 || Volume, 09 || Issue, 1 || January – 2019 ||
International Journal of Computational Engineering Research (IJCER)

Behavioural Study and Analysis of a Polycrystalline Solar PV Panel under varying Temperature and Irradiance

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ABSTRACT: *In rural India, electricity is an essential factor when it comes to the use for household, lighting along with various agriculture operations. Places like villages where installation of electrical grids become expensive, a smart technique of using renewable energies can be used for household purposes. In this paper, simulation model of PV module was designed and constructed in MATLAB/Simulink. The PV model (I) Current – (V) Voltage characteristics and also (P) Power – (V) Voltage characteristics were performed with different temperature and irradiance values. The paper highlights the effect of temperature and irradiance change on polycrystalline PV Panel. The results were shown in this paper for the simulated system which can be use for rural villages and domestic purposes.*

Date of Submission: 26-01-2019 Date of acceptance: 09-02-2019

I. INTRODUCTION

The modern society is very well depended on the electricity for their day to day work. Let it be the television or mobile or lighting etc. Consumption of electricity is being increased day by day which will result in a strong impact on the environment as well as human health. This happens most of the times since the energy are being produced using the coal or oil. These non-renewable methods results in more emission. Renewable energy sources generate zero or less carbon emissions when compared to the non-renewable sources. Use of these renewable source energies are in rise and are playing an important role in modern society. Out of all the renewable energies the solar is always available and free. The solar energy is converted to usable electricity through the solar cell or PV cell. Various PV cells constitute a single PV module generating electricity. These PV modules come in various powers according to the needed specification.

Working principle of Solar cell

The semiconductor devices such as PV solar cell absorbs the rays from the light which directly falls on the cell inclined at some angle. The absorbed photons are converted to the form of electricity which constitutes of electrons and holes. The figure 1 represents the basic cell of solar module.

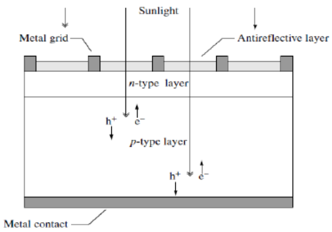

Figure 1 Basic cell of PV module

The rays or the sunlight passes through the metal grid which captures the sunlight. The antireflective layer doesn’t allow the rays to bounce back instead captures them. These photons are changed to the electrons or the holes which generated the electricity out of the solar cell. A PV cell generates maximum current when resistance in the system is zero. If a voltage in a circuit becomes zero then, the current is called (I_{sc}) short circuit current. In same circuit, if the voltage is high, then it is called (V_{oc}) open circuit voltage in which resistance becomes high and the current drops to zero. These variations with respect to the load as shown in below for photo voltaic model (I) Current – (V) Voltage characteristic curve.

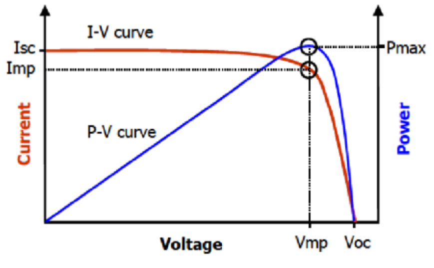

Figure.2 Photo Voltaic cell characteristics for (I) current – (V) Voltage (Courtesy: Google)

Another important graph for the PV module is the curve of Photo Voltaic is a product of (I) current and (V) voltage. Maximum power point is obtained at maximum current and voltage. Figure 2 represents the (P) Power – (V) Voltage characteristics of the Photo Voltaic cell. The performance of the Photo Voltaic cell can be done using I-V graph. The test conditions such as temperature of 25^0 and irradiance of $1000W/m^2$ are applied at the first to the PV module to evaluate its performance. In this paper, various temperatures and the irradiances where applied to determine the PV module performance with different graphs for (I) current – (V) voltage and (P) power – (V) voltage characteristics.

Electrical circuit of PV cell

Very simple representation for Photo Voltaic cell which can be represent with the electric side is shown in Figure. 3.

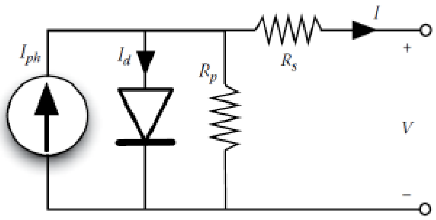

Figure.3 Photo Voltaic Cell equivalent circuit (Courtesy: Google)

One diode Photo Voltaic cell represents a cell with photon current induced through the semiconductor whose intensity depends, area of Photo Voltaic cell, irradiance and temperature level. Photo Voltaic cell characteristics is designed and implemented for the given below equation:-

$$I_{ph} = I_{phSTC} * \frac{G}{G_{STC}}[1 + \alpha_1(T - T_{STC})] \quad (1)$$

Where α_1 = coefficient of temperature in current which is:-

$$\alpha_1 = \frac{dI}{dT}|\text{at STC} \quad (2)$$

The above equations can be written in form of:-

$$I_{ph} = [I_{sc} + \{K_i * (T - 298)\}] * (\frac{G}{1000})(3)$$

The saturation current for the PV system is defined as:-

$$I_{sat} = C * T^3 * e^{\frac{E_{gap}}{KT}} \quad (4)$$

Where E_{gap} = band gap of the semiconductor

T = temperature

K = Boltzmann constant. The above equation can be written as:-

$$I_{sat} = I_{rs} * \left(\frac{T}{T_n}\right)^3 * e^{\left[\left(q*E_{g0}*\left(\frac{\frac{1}{T_n}-1}{T_n}\right)\right)/(n*K)\right]} (5)$$

Photo Voltaic (I) current – (V) voltage characteristics are written as:-

$$I = I_{ph} - I_{sat}\,(e^{\frac{V}{\eta V_t}} - 1) \quad (6)$$

Where, η = ideality constant of the diode and V_t = thermal voltage given by

$$V_t = \frac{KT}{q} \qquad (7)$$

For the accounting of ohmic losses the equation (6) for Photo Voltaic cell, (I) current – (V) voltage characteristics given below:-

$$I = I_{ph} - I_{sat}\left(e^{\frac{V}{\eta V_t}} - 1\right) - \frac{V*I_{rs}}{R_p} \qquad (8)$$

$$I = I_{ph} - I_0 * [e^{\left\{[V+I*R_s]*\left(\frac{q}{n*K*N_s*T}\right)-1\right\}} - I_{sh} \qquad (9)$$

Mathematical Modelling of PV module

Using the single diode PV module as shown in this paper, we construct the system in MATLAB/Simulink. By applying KCL to the equivalent system we obtain:-

$$I = I_{ph} - I_d - I_p \qquad (10)$$

Where I_p is the current through R_p as shown in the diagram.

Equation for the diode current can be given as:-

$$I_d = [e^{\frac{V+(I*R_s)}{\eta*V_t*Ns}} - 1] * I \qquad (11)$$

Where Ns= Total number of solar cells connected in series.

Shunt current is given by:-

$$I_p = \frac{V*I*R_s}{R_p} \qquad (12)$$

Reverse saturation current for the PV cell is given as:-

$$I_{rs} = \frac{I_{sc}}{e^{(\frac{q*V_{oc}}{\eta*K*T_c*N_s}-1)}} \qquad (13)$$

$$I_{rs} = I_{sc}/[e^{\left(\frac{q*V_{0c}}{n*N_s*K*T}\right)-1}] \qquad (14)$$

The parameters for the PV module are shown in table 1 for which the system was designed.

Table 1 Parameters for the Photo Voltaic module

Parameter	**Value**
Ambient Temperature	30^0C
Reference temperature (T_{ref})	25^0C
Electron charge (q)	1.6e-19
Boltzmann Constant (K)	1.38e-23
Diode identity factor(n)	1.5
Total number of cells (N_s)	36
Resistance in series (R_s)	0.221
Shunt Resistance (R_{sh})	415.406
Open Circuit Voltage (V_{oc})	21.6V
Short Circuit current	1.2
Power	$20W_p$

The MATLAB/Simulink model for the PV module was done using the equations (3), (5), (9) and (14) which have explained below.

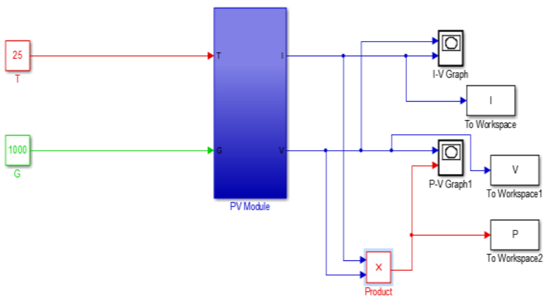

Figure.4 Photo Voltaic system model

Figure.4 represents the PV module system using the parameters and the equations defined. At the standard test conditions 25^0C and the irradiance of $1000W/m^2$ have been used to check the performance. Figure 5 represents the subsystem of the main system PV module. This subsystem consist of five more subsystems having shunt current, reverse saturation current, saturation current, PV current and photo current.

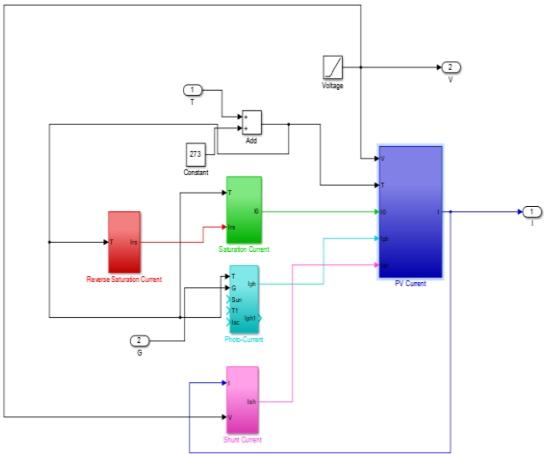

Figure.5 Subsystem of PV module

The saturation subsystem shown in figure 6 is modelled using the equation (5). The PV current subsystem shown in figure 7 is modelled using equation (9).

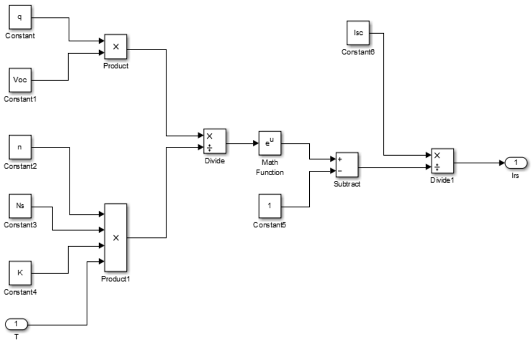

Figure.6 Saturation current subsystem

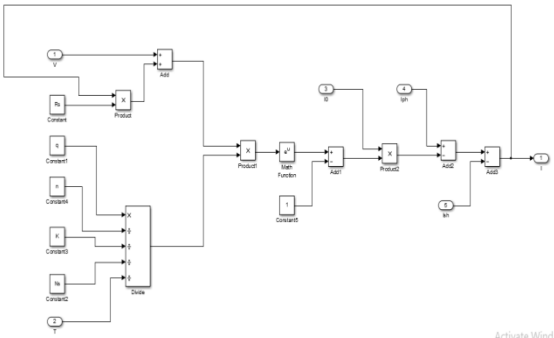

Figure.7 PV current subsystem

The photo current and the shunt current subsystems were modelled using the equations (12) and (13) respectively which are shown in figure 8 and figure 9. The reverse saturation subsystem is also shown in figure 10 which is built using the equation (14).

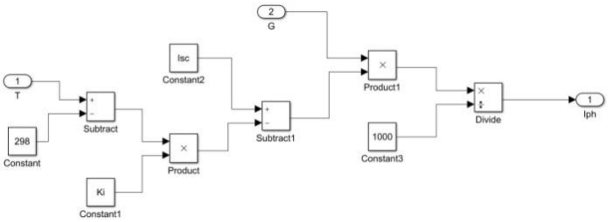

Figure.8 Photo current subsystem

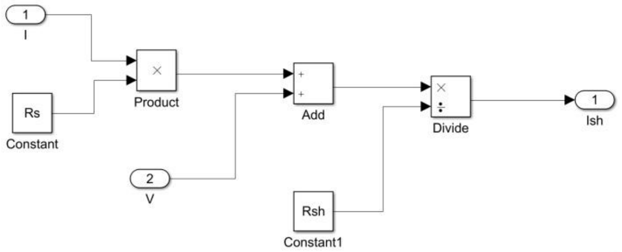

Figure.9 Shunt current subsystem

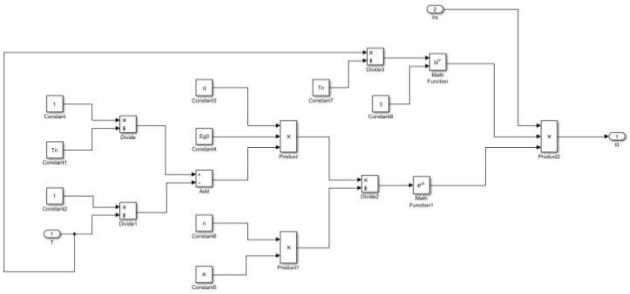

Figure.10 Reverse saturation current subsystem

II. RESULTS AND DISCUSSION

The PV system designed using the equations was run for the standard test conditions of 25^0C temperature and 1000W/m^2 irradiance to test the performance of the entire system. The (I) current – (V) voltage characteristics, the (P) power – (V) voltage characteristics are described in Figure.11 and also Figure.12 which match the basic waveform characteristics of the PV cell.

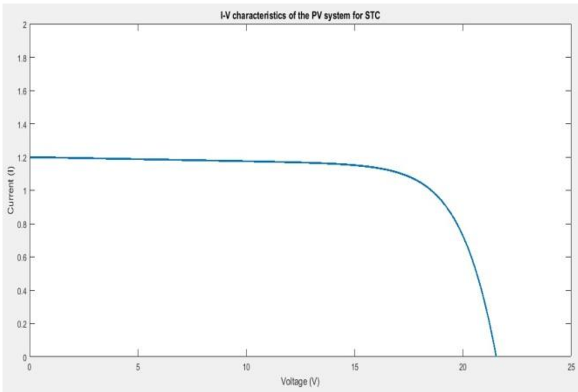

Figure.11 Photo Voltaic system (I) current – (V) voltage characteristics of for STC

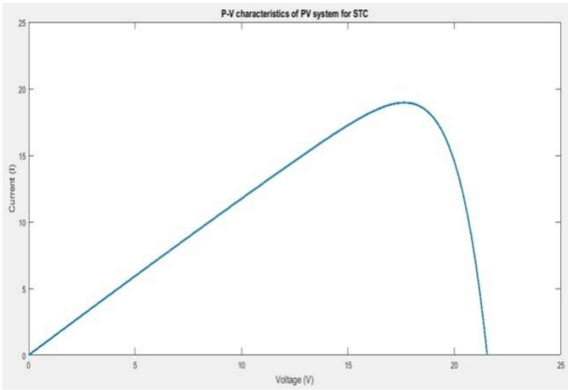

Figure.12 Photo Voltaic system (P) power – (V) voltage characteristics of for STC

As mentioned, in this paper, the PV system module was run for different temperature values (keeping irradiance constant at 1000W/m^2) and for different irradiance values (keeping temperature constant at 25^0C). Figure.13 and

14 represents the (I) current – (V) voltage characteristics and (P) Power – (V) Voltage characteristics for the Photo Voltaic system simulated for various temperature values(keeping irradiance constant at $1000 W/m^2$) varying from 5^0C to 55^0C in the interval of 10^0C respectively.

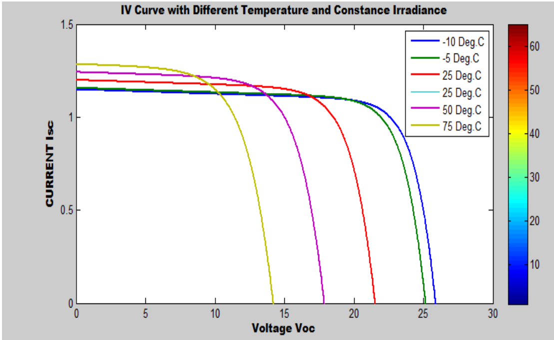

Figure.13 Photo Voltaic system (I) current – (V) voltage characteristics for various temperatures keeping constant irradiance

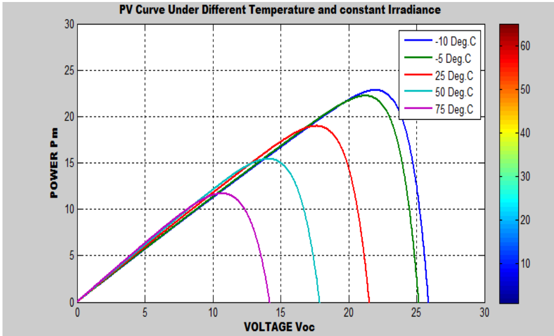

Figure.14 Photo Voltaic system (P) power – (V) voltage characteristics for various temperatures keeping constant irradiance

Figure.15 and 16 represents the (I) current – (V) voltage characteristics and (P) power – (V) voltage characteristics of Photo Voltaic system for various irradiance values (keeping temperature constant at 25^0C) ranging from $700W/m^2$ to $1200W/m^2$ for the interval of $100W/m^2$ respectively.

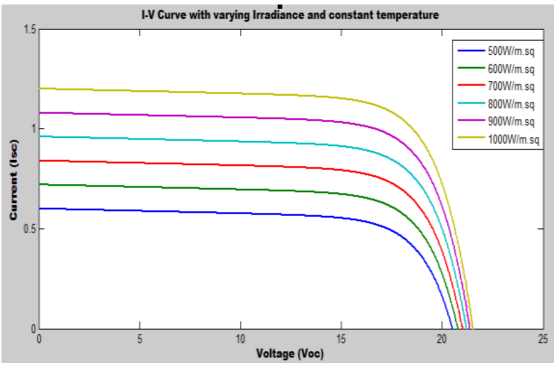

Figure.15 Photo Voltaic system (I) Current – (V) Voltage characteristics with various irradiances keeping temperature constant

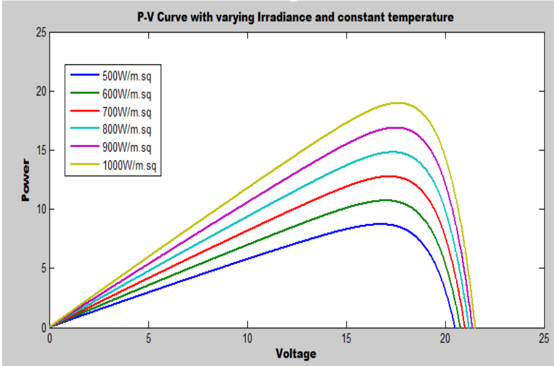

Figure 16 Photo Voltaic system (P) Power – (V) Voltage characteristics with various irradiances keeping temperature constant

As seen from the waveforms obtained, the Photo Voltaic system characteristics are designed with various values of temperature and irradiance are in accordance with the fundamental waveform/characteristics of the basic PV solar system.

III. CONCLUSION

Electricity is an essential factor when it comes to the use for household, lighting along with various day to day operations. Places like villages where installation of electrical grids become expensive, a smart technique of using renewable energies can be used for household purposes. In this paper, simulation model of PV module was designed and constructed in MATLAB/Simulink. The PV module's (I) current – (V) voltage characteristics and also (P) Power – (V) Voltage characteristics were simulated and obtained with different temperature and irradiance values. The results obtained show that the system designed and implemented in MATLAB/Simulink is in unity with the fundamental PV solar cell characteristics.

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S R Prasad" Novel Variable Step Size Complementary Pair Least Mean Square (VSS-CPLMS) Algorithm for System Identification" International Journal of Computational Engineering Research (IJCER), vol. 09, no. 1, 2019, pp 01-07