MATLAB SIMULATION OF PHOTOVOLTAIC MODULE BY SOLVING ALGEBRAIC LOOP ERRORS

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ABSTRACT

The recent upsurge in the demand of Photovoltaic (PV) systems is due to the fact that they produce electric power without hampering the environment by directly converting the solar radiation into electric power. Extensive works exist in literature about modeling solar power generation by photovoltaic module. However, some fundamental aspects of the design making it flexible and expsssssloitable for other research works remain difficult and unclear under Matlab Simulink. This work proposes an understandable model of PV module, suitable for upgradability and further use for other designs. After dealing with a sound analytical model on the PV module, the paper presents a clear modeling under Simulink. However this paper presents a simple technique of simulation of photovoltaic module in application of single module and observe the I-V, P-V Characteristics which is done in MATLAB-SIMULINK environment based on PV module model in which the basic circuit equations are used in the Photovoltaic (PV) cells including the effects of solar irradiation and temperature changes. These results, further confirm the novelty of the proposed model.

*Keywords***:** *Photovoltaic, PV Module, Algebraic Loop Error*

I INTRODUCTION

The concentration on the use of fossil fuels for energy supply is the main threat for the stability of the global climate system and our natural living conditions. To conserve our globe, the scientific community gave evidence that mankind has to decrease the green house gases emissions, mainly CO2 and methane, by 60 - 70% as a minimum until the year 2050[2]. In order not to harm our natural living spaces and threaten their resilience, a renewed compatibility would require a suitable form of energy alternatives sources that should be independent, easily accessible, and low in cost and should be environmentally clean.

Renewable energy, and in particular power generation from solar energy using Photovoltaic (PV) has emerged in last decades since it has the aforesaid advantages and less maintenance, no wear and tear. The main applications of PV systems are in stand-alone systems such as water pumping, domestic and street lighting, electric vehicles, military and space applications or grid-connected configurations like hybrid systems and power plants [2].

The main aim of this project is to provide a reader with the fundamental knowledge on design and building the blocks of PV module based on the mathematical equations using MATLAB/Simulink.

1.1 Modelling of PV Module

The building block of PV module is the solar cell, which is basically a p-n junction that directly converts light energy into electricity. The ideal photovoltaic cell is shown in figure 1. [2]

The mathematical equation for I-V characteristics of the ideal cell is given by equations (1), (2) [2].
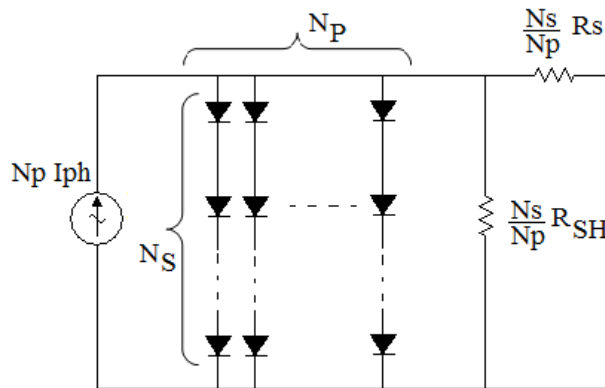
$$I = Ipv - Id \qquad (1)$$
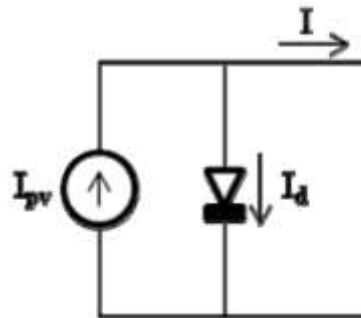
Fig. 1: Equivalent circuit of Ideal PV Cell.[2]

Where, Id is the Shockley equation and it can be expressed as

$$Id = Is\left\{exp\left(\frac{q}{AkTc}\right) - 1\right\} \qquad (2)$$

Based on the general model of solar cell illustrated in figure 3.2, a solar panel which is a combination of Ns and Np solar cells put in series and parallel respectively, can be modeled as shown in Figure 2.[7]

Fig. 2: Model of solar panel with Ns series cell and Np parallel cells[7]

Consequently, the following equations (1-4), hold:

$$I = NpIph - NpIs\left[exp\left(\frac{q}{kTcA}\cdot\left(\frac{V}{Ns} + \frac{IRs}{Np}\right)\right) - 1\right] - \frac{1}{Rsh}\cdot\left(\frac{NpV}{Ns} + IRs\right) \ldots\ldots\ldots\ldots (1)$$

With:

$$Iph = [Isc + Ki(Tc - Tref)]G \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$Is = Irs\left(\frac{Tc}{Tref}\right)^3 \exp\left[\frac{qEg\left(\frac{1}{Tref}-\frac{1}{Tc}\right)}{kA}\right] \qquad \text{...} (3)$$

And

$$Irs = \frac{Isc}{\exp\left[\left(\frac{qVoc}{kATc}\right)-1\right]} \qquad \text{.......................................} (4)$$

Where

- *Iph:* photocurrent

- Is: Cell saturation current

- q: Electron charge. q = 1.6 * 10^{-19}C

- k: Boltzmann's constant. k = 1.38 *10^{-23}j/K

- Tc: Cell operating temperature.

- A: Ideal factor dependent of the PV characteristic, A=1.3 for poly-crystalline solar cell

- Rsh: Shunt resistance.

- Rs: Series resistance.

- Isc: Cell short-circuit current at 25°C, 1kW/m2

- Voc: Open-circuit voltage

- ki: Short-circuit current temperature coefficient

- Tref : Cell reference temperature

- G : Solar insolation (irradiance) in kW/m2

- Irs: Cell reverse saturation current

- Eg: Band gap energy of semiconductor used in a cell = 1.11eV

- Np: Number of cells in parallel=1

- N$_S$: Number of cells in series= 1

A certain number of solar cells, Ns are put in series and a certain number of them, Np are put in parallel in order to achieve some levels of voltage and current that are convenient for applications. The combination of Ns and Np solar module put respectively in series and in parallel constitutes a solar panel.

In addition, Table 1 gives some intrinsic characteristics of PV module, extracted from manufacturer data that would be used for the Simulink modeling:

Table 1: Parameters value used in MATLAB/SIMULINK

PARAMETERS	VALUES
Short-circuit current(Isc)	3.8A
Open circuit voltage(Voc)	21.1V
Electron charge(q)	1.6022* 10-19 C
Ideal factor(A)	1.3
Band gap energy of semiconductor(Eg)	1.11 eV
Boltzmann's constant(k)	1.38*10-23j/K

Temperature coefficient of short-circuit current(Ki)	0.047m A/^{0}C
Cell Reference temperature (Tcref)	25 ^{0}C
Cell operating temperature(Tc)	26^{0}C
Number of module in parallel (Np)	1
Number of module in series(Ns)	1
Shunt resistance(Rsh)	100Ω
Series resistance(Rs)	0.01 Ω
Solar irradiance(G)	4kW/m^2

II. EXPERIMENT AND RESULT

2.1 Simulink PV Model Developments

Using the equations given in above section, Simulink modeling is done as explained in the following steps:

Step- 1: Using equation no. 2, the photo generated current is modeled.

Step- 2: Using equation no. 3, the saturation current is modeled.

Step- 3: Using equation no. 4, the reverse saturation current of the module is modeled.

Step- 4: The output current of the module is modeled using equation no. 1.

Step- 5: The four models are finally interconnected as shown in Figure 4.

Using the Simulink simulation tool, the model of photovoltaic module illustrated in Figure 3 was first obtained.

2.2 Algebraic Loop Errors

This was not able to be run directly under Simulink because of the presence of two algebraic loops. Algebraic loop error appears when an output is directly dependent on the combination of other inputs and itself. This transpires through equations having the same output parameter on both side of the equal sign. For instance, if we reconsider equation (1) as follow

$$I = I1 - I2 - \frac{1}{Rsh} \cdot \left(\frac{NpV}{Ns} + IRs \right) \tag{5}$$

With $I1 = NpIph$

And $I2 = NpIs \left[\exp\left(\frac{q}{kTcA} \cdot \left(\frac{V}{Ns} + \frac{IRs}{Np} \right) \right) - 1 \right]$ (6)

The variable I appears on both side of the equation (5) creating an algebraic loop in Simulink. Also the second part of equation (6) also shows an exponential function having the same parameter I as its input. This is a second algebraic loop appearing in our model (see Figure 4).

III SOLUTION OF ALGEBRAIC LOOP ERRORS

3.1 To solve the first algebraic loop, the equation has been rewritten as follow:

$$I\left(1+\frac{Rs}{Rsh}\right) = I1 + I2 - \frac{1}{Rsh} * \frac{NpV}{Ns}$$

And the value of I is inferred:

$$I = \frac{1}{1+\frac{Rs}{Rsh}} * \left(I1 + I2 - \frac{1}{Rsh} * \frac{NpV}{Ns}\right) \qquad (8)$$

This practice help to eliminate the first algebraic loop but the second one contained in the expression of I_2 still exists and shows up with the error message below at the running of the simulation:

Warning: Block diagram 'initialwithnsnp' contains 1 algebraic loop(s). To see more details about the loops use the command line Simulink debugger by typing "sldebug initialwithnsnp" in the MATLAB command window. To eliminate this message, set the Algebraic loop option in the Diagnostics page of the Simulation Parameters Dialog to "None"

Found algebraic loop containing:

  'initialwithnsnp/Product1' (algebraic variable)

  'initialwithnsnp/Sum'

  'initialwithnsnp/Divide1'

  'initialwithnsnp/Product8'

  'initialwithnsnp/Divide6'

  'initialwithnsnp/Sum8'

  'initialwithnsnp/Divide10'

  'initialwithnsnp/exp1'

  'initialwithnsnp/Sum9'

  'initialwithnsnp/Product9'

  'initialwithnsnp/Sum1' (algebraic variable)

3.2 The second algebraic loop was finally solved by inserting a delay block in the feedback loop coming from the output I before entering the exponential block so that the current value can be calculated based on the previous one.
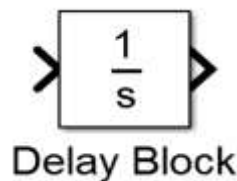
Figure 3: Delay block

With all these changes, the model of Figure 4 has been improved to become Figure 5 which simulates without error and produce convenient results.

IV HOW TO PLOT THE CHARACTERISTICS CURVES OF MODEL

We can plot the results of various simulation by writing short code in Matlab command window. A multiplexer was

used in Figure 5 to collect the results produced by simulation into a variable "Vout" that is later used to plot the different curves under Matlab command mode.

>> V=Vout(:,1);

>> I=Vout(:,2);

>> P=Vout(:,3);

>> figure(1)

>> %clf

>> plot(V,I),xlabel('voltage'),ylabel('current'),title('current characteristic'),grid on, hold on, axis([0 25 0 30]);

>> figure(2)

>> %clf

>> plot(V,P),xlabel('voltage'),ylabel('power'),title('power characteristic'),grid on, hold on, axis([0 30 0 400]);
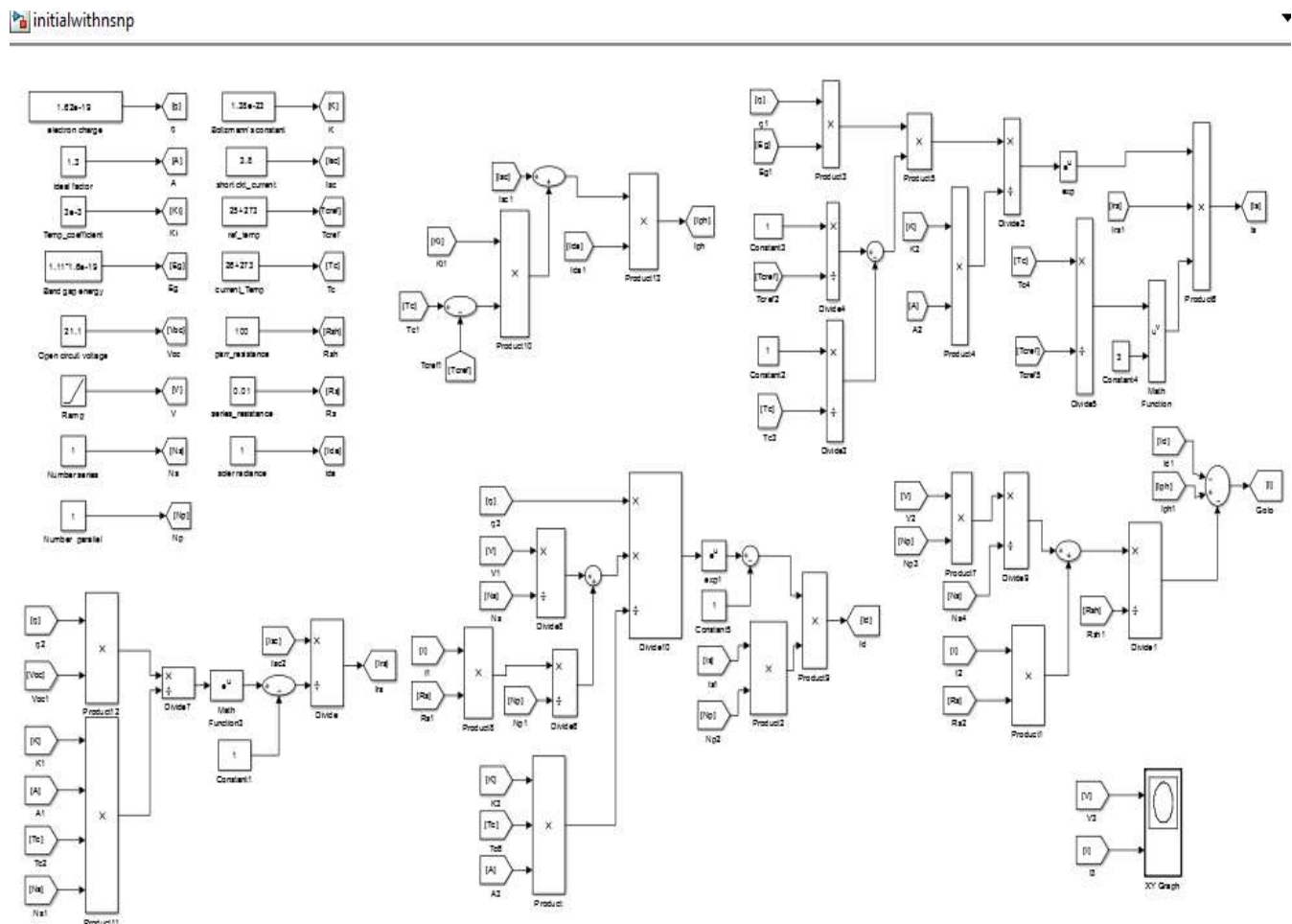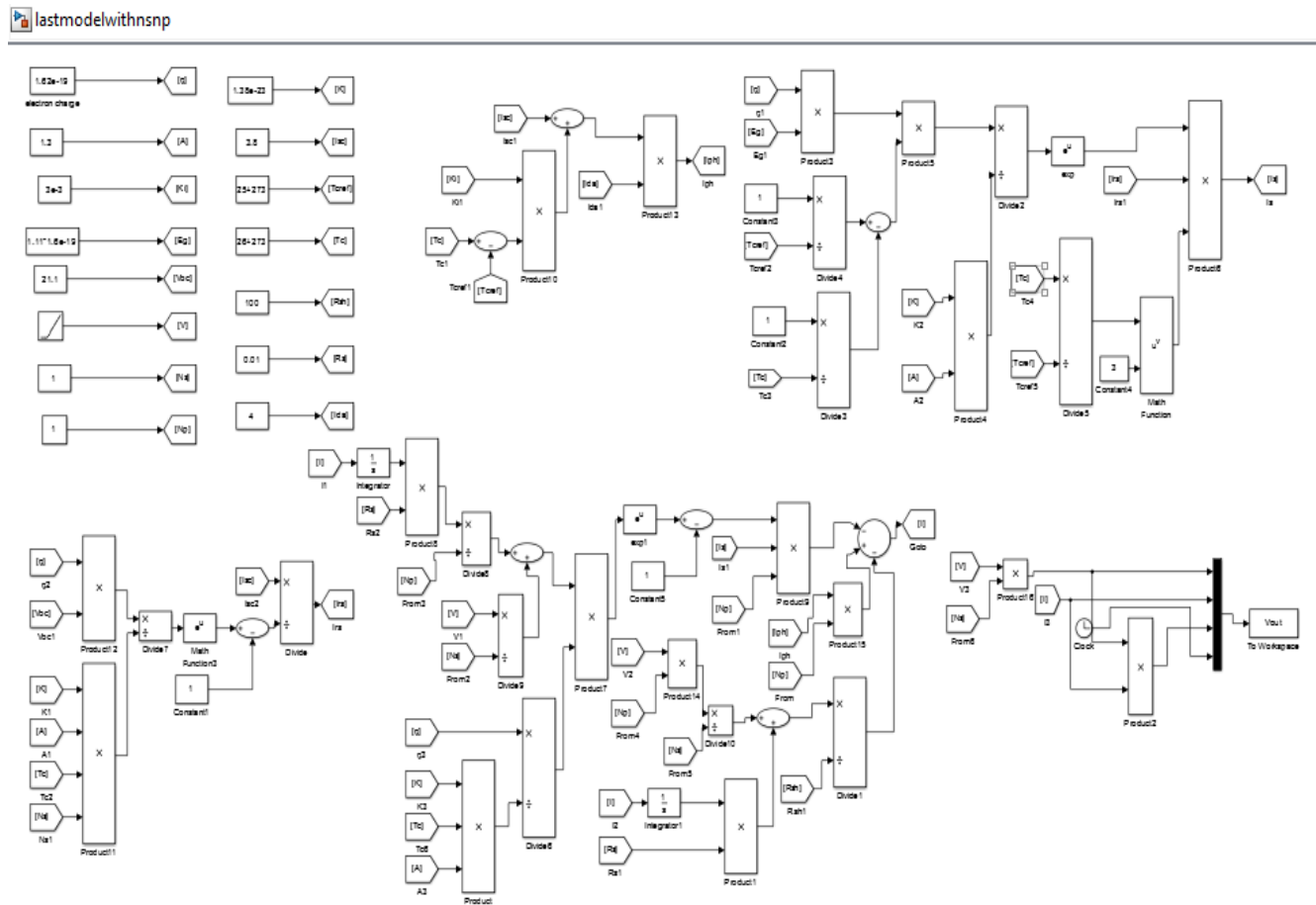

Fig 4: Initial Model of Solar module under Matlab/Simulink

Fig 5: Improved Model of solar module under Matlab/Simulink

V RESULTS

5.1 Output Waveforms Of The PV Module

The waveforms obtained by varying the solar insolation and temperatures which are fed into the PV Module model have been plotted as shown below:

- First the temperature was kept constant and the insolation was varied within a reasonable range.
- In second instance, the insolation was kept constant whilst the temperature was varied to show the effect of solar radiation on PV cells.

5.2 Current Characteristics For Constant Temperature

The current characteristics of the designed model for a fix temperature of 26^oC and for varying values of irradiation between the ranges of 4 to $6kW/m^2$ are shown in figure (a).

From Figure (a), we observed that the as the irradiation increases, the constant value of the current also increases but the threshold voltage reduces slightly.
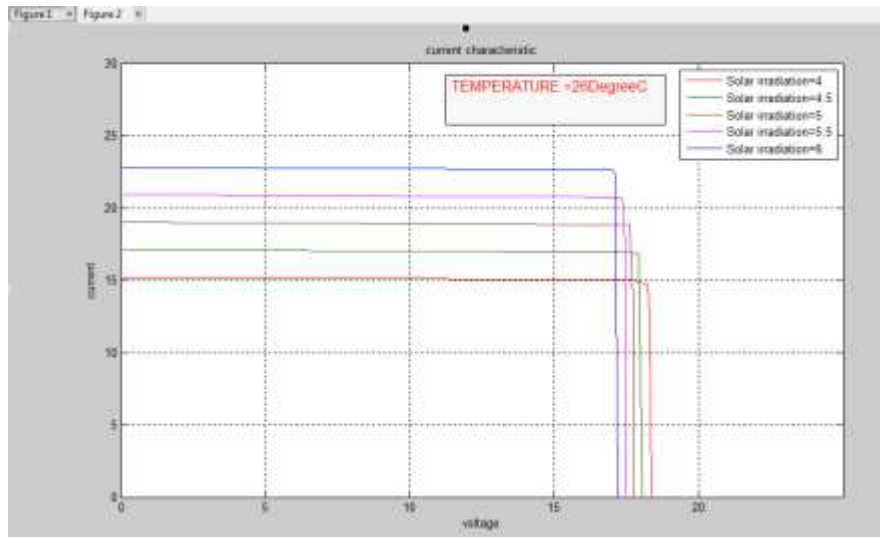
Figure (a): I-V curves obtained at 26^0C for various irradiance levels

5.3 Power Characteristics for Constant Temperature

Figure (b) shows the power characteristics of our model for a fixed temperature of 26^0 C and for varying values of irradiation between the ranges of 4 to 6kW/m^2. Again increasing solar irradiation impact positively on the power characteristic producing higher power for a constant voltage.

5.4 Current Characteristics for Constant Irradiance:

Furthermore, the irradiance was kept constant and the temperature was varied apart from the standard temperature in order to determine the effect on the results. Figure (c) and Figure (d) show the impact of temperature variation on the model. It appears that the model develops some small sensitivity to big variation of temperature. However, this effect is negative i.e. as the temperature increases the current and the power characteristics decrease.

From figure (c), we observed that by increasing the temperature level at constant irradiance, the voltage output from PV module decreases but current output increases slightly with respect to voltage.

5.5 Power Characteristics For Constant Irradiance:

We observed that by increasing the temperature level at constant irradiance, the voltage output from PV module decreases and, hence the power output from PV module decreases.
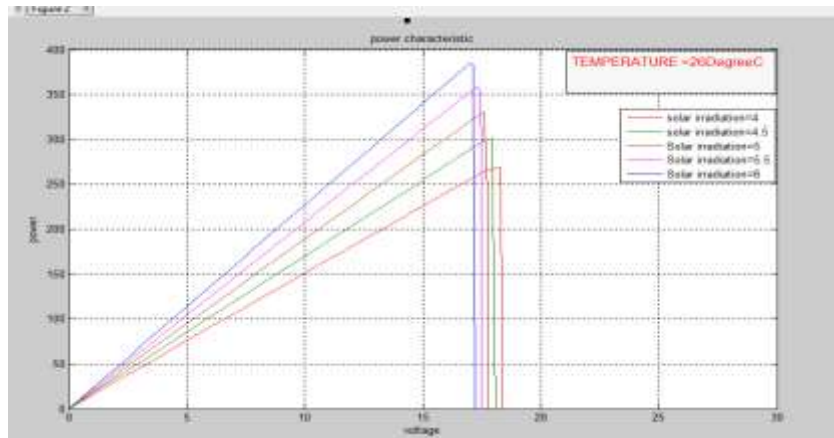
Figure (b): P-V curves obtained at 26^{0}C for various irradiance levels
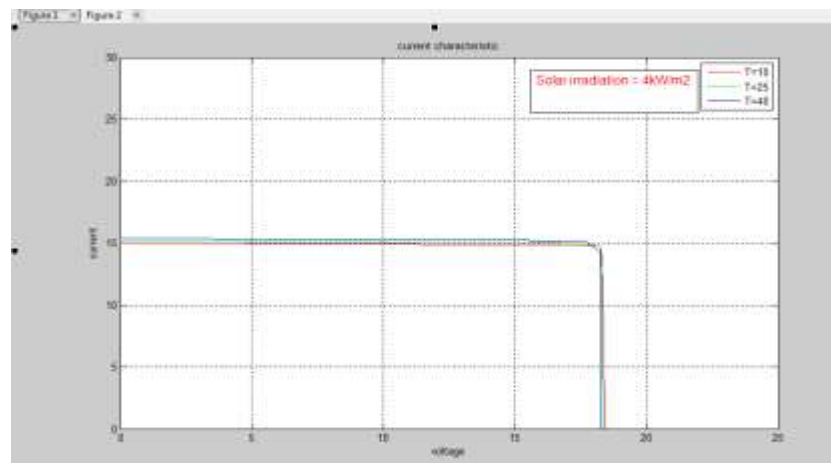

Figure (c): I-V curves obtained at an irradiance of 4 kW /m2 for various temperatures.
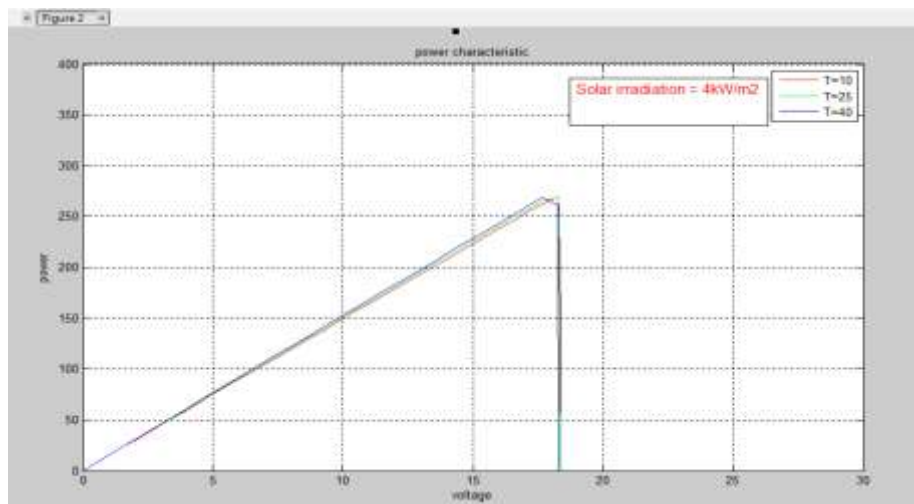

Figure (d) P-V curves obtained at an irradiance of 4 kW/m2 various temperatures.

IV.CONCLUSION

This paper dealt with the modeling of Photovoltaic module through photovoltaic effect. A model presented with equations in first instance was later constructed under Matlab/Simulink and simulated for two effects: varying irradiance and varying temperature. The developed model was firstly not simulating successfully because of the presence of two algebraic loops. However, the model has been later improved with a comprehensive solution to the two algebraic loops. One was solving by insertion of delay block while the other was solve by a re-working of necessary formula.. This results obtained in form of two fundamental graphs namely power characteristic (power over voltage) and current characteristic (current over voltage) are very similar to empirical results known for solar system and this, further confirms the effectiveness of the proposed model.

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