ISSN 2229-5518

Different methods of modeling a photovoltaic cell using Matlab / Simulink / Simscape

Mehimmedetsi Boujemaa
Laboratoire d'électrotechnique MoDERNa
University of Constantine
Constantine, Algeria
monir_ifp@yahoo.fr

Chenni Rachid
Laboratoire d'électrotechnique MoDERNa
University of Constantine
Constantine, Algeria
rachid.chenni@yahoo.fr

Abstract-The objective of this work consists on studying various models that exist in literature for modeling solar cells. Our effort is focused on modeling PV array Implemented in the Matlab / Simulink environment using the Toolbox Simscape / SimElectronics.

Keywords: photovoltaic;Simscape;SimElectronics; SimPowerSystems; different model.

I. Introduction

Renewable energy offer new solutions to energy demand which continues to grow and can bring new forms of energy; they are, until now, additional sources of energy. Renewable include a number of technological fields according to the source of energy used and of the energy obtained. The study sector in this paper is *solar photovoltaic*. Photovoltaic energy can be considered as the most attractive among the other types of renewable energy, it has many advantages such as:

- Solar energy is everywhere, clean, free and silent.
- A modular power installed as required.
- A decentralized operation without network.
- No fuel, no greenhouse gas emissions, minimal maintenance, a long lifetime of PV generators (nearly 20 years).
- It produces electricity directly, high energy value, so we can count on its performance.
- It can be applied either for supplying a mobile phone or as a part of a 500 kW power plant.

A solar cell generates electrical energy by direct conversion of solar radiation to direct current by use of semiconductor materials made of monocrystalline, polycrystalline or amorphous silicon [1].

II. SOLAR GENERATOR MODELING

The scientific community offers several models to model the PV generator. The standard model with one diode for a single cell, we generalize then the model to a PV module by considering it as a set of connected identical cells in series-parallel is commonly used Fig. (1a).

The equivalent circuit of the general model, which consists of a current source, a diode, a parallel resistance due to leakage currents and a series resistance describing an internal resistance when the current flows Fig. 1a. [2].

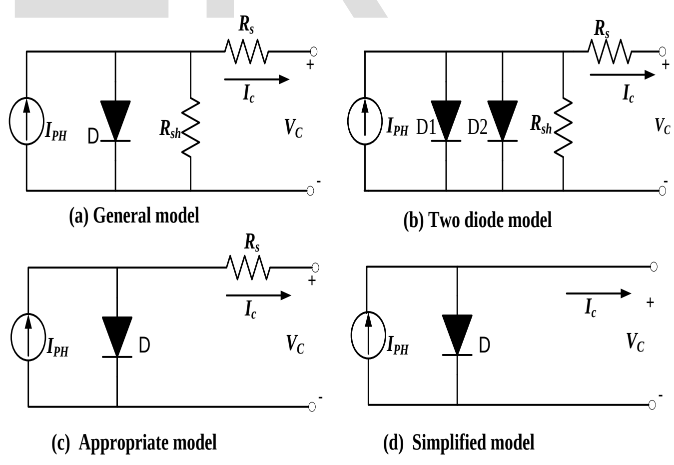

Fig.1. Different model of the PV generator

The electrical energy produced by a solar cell depends on the illumination it receives on its surface; the voltage-current characteristic equation of a solar cell is given by the application of the first Kirchhoff's law, so we write:

ISSN 2229-5518

$$I_g = I_{ph} - I_D - I_{sh}$$
$$= I_{ph} - I_0\left(\exp\left(\frac{q\left(V_g + R_S I_g\right)}{nkT_C}\right) - 1\right) - \frac{\left(V_g + R_S I_g\right)}{R_{Sh}} \quad (1)$$

For a photovoltaic generator consists of series *Ns* and parallel cells *Np* cells (1) becomes [2] [3]:

$$I_g = N_P\left(I_{ph} - I_0\left(\exp\left(\frac{q\left(\frac{V_g}{N_S} + R_S\frac{I_g}{N_P}\right)}{nkT_C}\right) - 1\right) - \frac{\frac{V_g}{N_S} + R_S\frac{I_g}{N_P}}{R_{sh}}\right)$$

(2)

V_g, I_g: Voltage [V] and current [A] panel output.
Iph: Photocurrent in [A].
R_s series resistance, R_{sh} shunt resistance in ohms.
q the electron charge q = $1.602.10^{-19}$ coulomb.
k Boltzmann's constant k = $1.381.10^{-23}$ J / K.
n quality factor of the diode, between 1 and 2.
The shunt resistance *Rsh* is considerably high, the current *Ish* tends to zero the above equation becomes [Fig. 1-c]

$$I_g = I_{ph} - I_D = I_{ph} - I_s\left(\exp\left(\frac{q\left(V_g + R_S I_g\right)}{nkT_C}\right) - 1\right) \quad (3)$$

For an ideal cell *Fig.1.d Rsh* and *Rs* can be neglected. (3) can be simplified to [3]:

$$I_g = I_{ph} - I_D = I_{ph} - I_s\left(\exp\left(\frac{qV_g}{nkT_C}\right) - 1\right) \quad (4)$$

For many cells the equation (4) becomes:

$$I_g = N_P\left(I_{ph} - I_s\left(\exp\left(\frac{qV_g}{N_s nkT_C}\right) - 1\right)\right) \quad (5)$$

The current source depends mainly on the radiation and the operating temperature of the cell, which is described as follows [6] [8]:

$$I_{PH} = \frac{G}{G_{ref}}\left[I_{sc} + \mu_{I,SC}\left(T_c - T_{c,ref}\right)\right] \quad (6)$$

Isc represents the short-circuit current of the cell at 25 ° C and 1kW/m^2.

$\mu_{I,SC}$ Temperature coefficient of the cell short circuited, $T_{c,\,ref}$ is the reference temperature of the cell, and *G* is the solar radiation in W/m^2, in other hand the saturation current varies with the temperature of the cell, it is described as follows:

$$I_s = I_{s,ref}\left(\frac{T_c}{T_{c,ref}}\right)^{\frac{3}{n}} \exp\left[\frac{qe_{gap}}{nk}\left(\frac{1}{T_{c,ref}} - \frac{1}{T_c}\right)\right] \quad (7)$$

$$I_{s,ref} = \frac{Isc}{\left(\exp\left(q\frac{V_{oc}}{nkT_{ref}}\right) - 1\right)} \quad (8)$$

$I_{s,ref}$: current of reverse saturation at the reference temperature.
e_{gap} the width of the band-gap of the semiconductor material, for the silicon, it is equal to 1.11 eV
The temperature of the cell is calculated by:

$$T_c = T_a + \frac{G}{800}\left(NOCT - 20\right) \quad (9)$$

T_a: Ambient temperature in ° C.

NOCT the nominal operating cell temperature in ° C.

The two diodes model is widely used when we want more precision where the equivalent circuit is shown in Fig. 1-b. [4] [5]

The characteristic I (V) is done by:

$$I_g = I_{PH} - I_{D1} - I_{D2} - I_{Rh} =$$
$$I_{PH} - I_s\left(\frac{q\left(V_g + R_S I_g\right)}{nkT_C} - 1\right) - I_{s2}\left(\frac{q\left(V_g + R_S I_g\right)}{n_2 kT_C} - 1\right) - \frac{\left(V_g + R_S I_g\right)}{R_{Sh}}$$

(10)

I_s and I_{s2} are the current of reverse saturation of the diode 1 and diode 2. n is the quality factor (diode's emitting coefficient) of the first diode. n_2 is the quality factor of the second diode. The equation of the PV generator with N_s cells in series and *Np* cells in parallel:

$$I_g = N_p I_{PH} - N_p I_s\left(\frac{q\left(\frac{V_g}{N_s} + R_S\frac{I_g}{N_p}\right)}{nkT_C} - 1\right) - N_p I_{s2}\left(\frac{q\left(\frac{V_g}{N_s} + R_S\frac{I_g}{N_p}\right)}{n_2 kT_C} - 1\right)$$
$$- \frac{N_p\left(\frac{V_g}{N_s} + R_S\frac{I_g}{N_p}\right)}{R_{Sh}} \quad (11)$$

III. IMPLENTATION OF THE PHOTOVOLTAIC GENERATOR IN SIMULINK

Several studies exist to model the PV generator under Matlab / Simulink environment. the resolution of the mathematical equation of the PV generator requires the use of numerical methods for the equation $I_{pv} = f\ (U_{PV})$ which is nonlinear and dependent on solar illumination.

A. Model using the "MATLAB function" under Simulink environment

This method includes the MATLAB program written in ".m" in *MATLAB function*. The program is compiled in *C language* and then run. [4], [6].

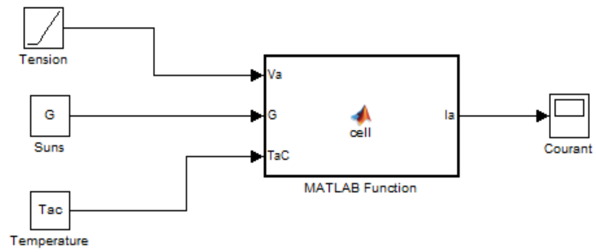

Fig.2. Solar Cell Model in Matlab / Simulink "Embedded MATLAB Function"

B. Model developed in Simulink environment / SimPowerSystems.[7]

This method uses the biblioteque SimPowerSystems / Simulink, a photovoltaic array is made up of a group of PV module, we can implanted the PV array (Fig.3) or implanted one solar cell (Fig.4) then generalize the PV module and then PV array.

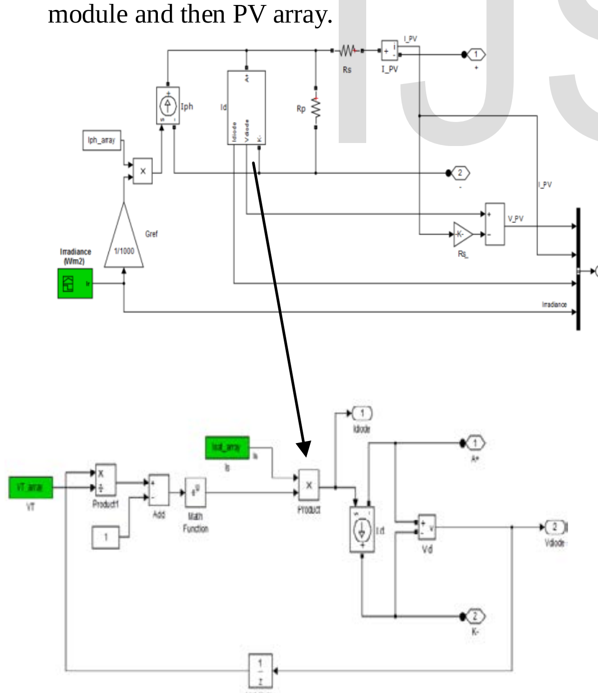

Fig.3. Model of a PV Array in the Simulink / SimPowerSystems.

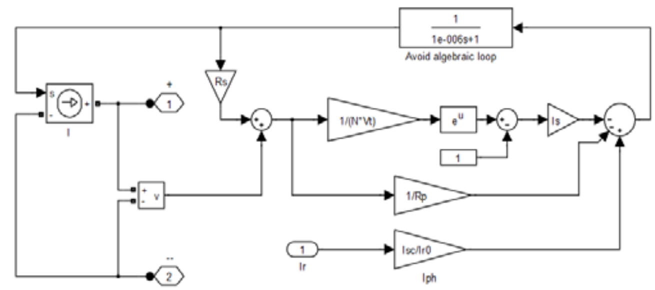

Fig.4. Model of a PV cell in the Simulink / SimPowerSystems

C. Model using the simulink block in the environment Simscape / SimElectronics:

This method utilize physical components in simscape
This block is a black box with a hidden code, we put preselected panel settings. [9]
The block can has 3 settings:
- 5 parameters: I_{SC} ,V_{OC} ,I_{R0} ,n, R_S
- 5 parameters: I_S ,I_{PH0} , I_{R0} ,n, R_S
- 8 parameters: I_S , I_{S2} , I_{PH0} , I_{R0} ,n, n_2,R_S , R_{sh}

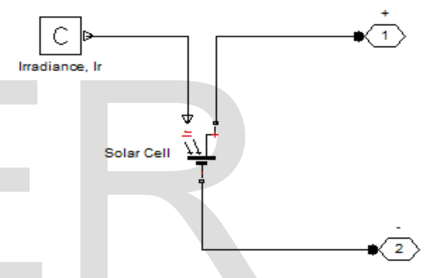

Fig.5. block of a PV cell under Simscape / environment SimElectronics

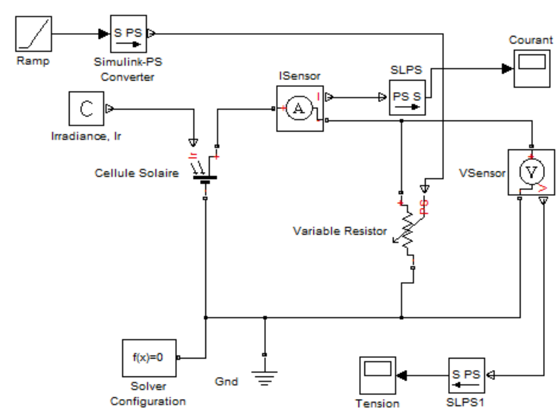

Fig.6. PV Cell modeling in Simscape SimElectronics environment

From the block Simscape for a unit cell, we can build a Photovoltaic Module.

The blocks are composed of six solar cells connected in series. Our module consists of 36 cells, so we have 6 blocks of 6 cells. The short-circuit current of the module is equal to the short circuit in each cell.

ISSN 2229-5518

The open circuit voltage of each block is obtained by dividing the open circuit voltage of the module by the number of block circuit.

The series resistance of each block is obtained by dividing the series resistance of the module by the number of block.

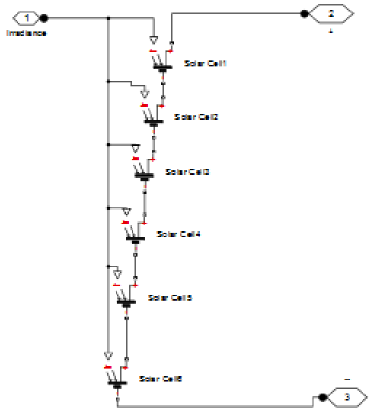

Fig.7. connection of 6 cells in series with Simscape

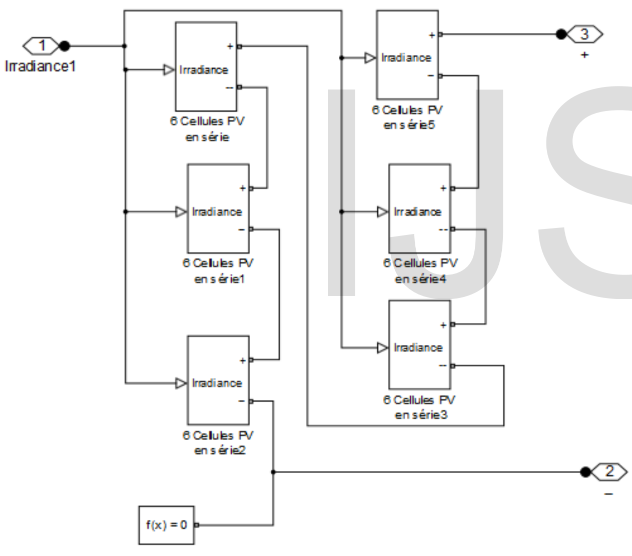

Fig.8.Building the Photovoltaic module (36 cells)

D .Model using physical elements

This model is developed from physical elements using Simscape / SimElectronics. The circuit contains (a current source, two resistors and a diode); the equivalent circuit diagram of the solar cell is represented by the following circuit [5].

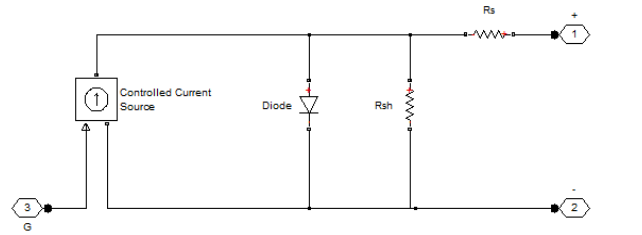

Fig.9. Equivalent circuit of a cell in Simscape / SimElectronics environment

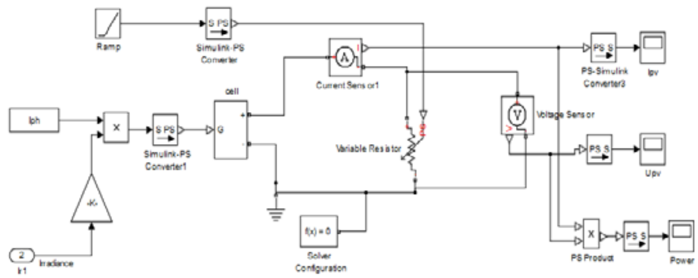

Fig.10. Modeling of the PV cell under the environment Simscape / SimElectronics with a variable resistor

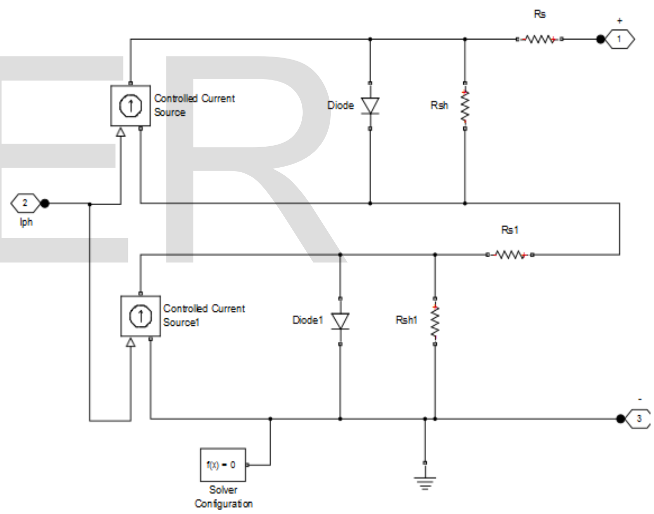

Fig.11. Example of two cells in series connection with SimElectronics

The modeling of the cell with a variable resistor as load [Fig.7] provide features $I_{pv}=f\,(U_{pv})$ and $I_{pv}=f$ (power). [10].

ISSN 2229-5518

E.Model using bloc function in Simulink

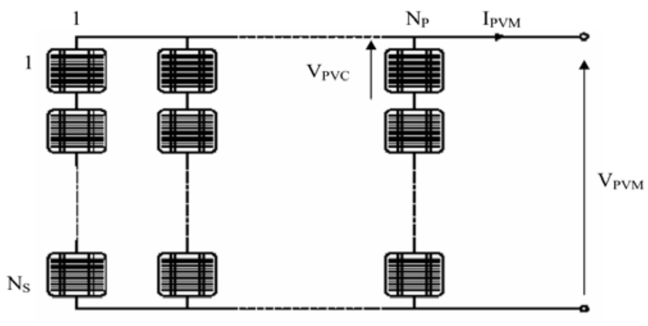

Fig.12. configurations of PV array

This method was developed to the PV Array generator from the library simulink especially the block function.

The modules in a PV system are typically connected in arrays. (Fig.9) illustrates the case of an array with M_P parallel branches each with M_S modules in series.

The equation for a PV module can be expressed by using the one-diode PV cell model as follows: N_s = number of cells in series and N_p = number of cells parallel. [12].

$$V_{PVM} = N_S V_{PVC}$$

$$I_{PVM} = N_S I_{PVC}$$

Where M designates a PV module and C designate a PV cell. PV modules are coupled together form a PV array. The equation for a PV array can be expressed by adapting the PV module's equation as follows:

$$V_{PVA} = M_S N_S V_{PVC}$$

$$I_{PVA} = M_P N_P I_{PVC}$$

M_s is PV module series and M_p is PV module parallel.

By using general model fig.1 and applied equations. (3), (6), (7), (8), (9) and (10) we have established different block of the PV generator in *SimPowerSystems/* Simulink.

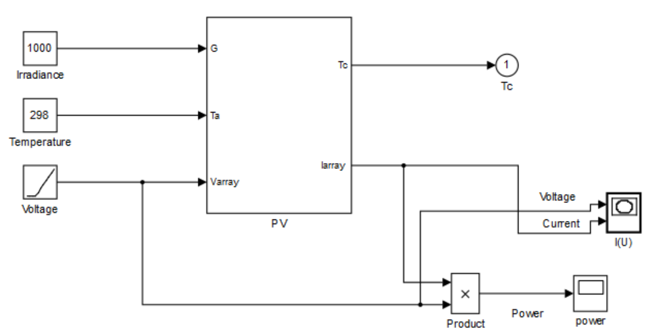

Fig.13. Implementation the PV array in the SimPowerSystems/Simulink

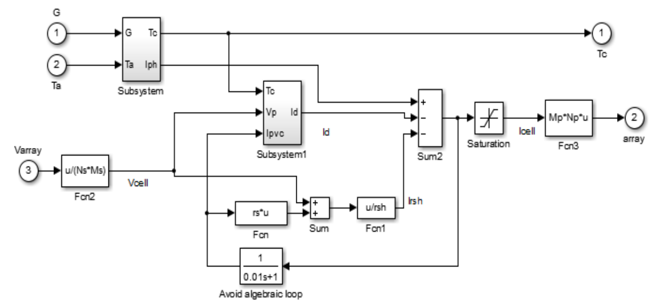

Fig.14. Masked block PV array

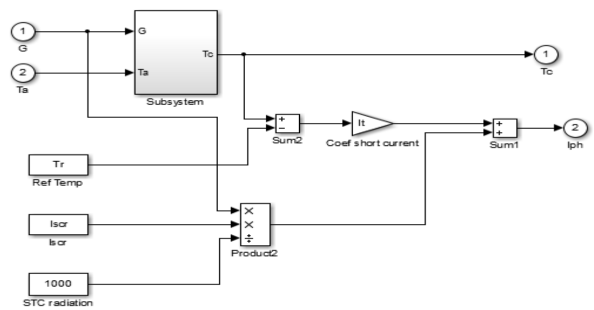

Fig.15. Calcul block current and temperature (Tc) of the PV Array

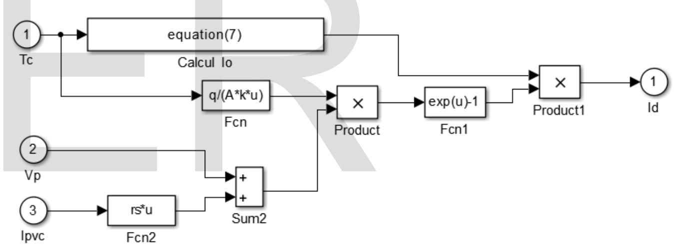

Fig.16. calaculation of diode current Id

E. Model using experimental data

In the following model, we use from experimental data we can build the PV panel using 2D Lookup Table from simulink in simulation.

The model has two inputs irradiance and current, the output is the voltage. Correcting the temperature affects the voltage that is fed to the output of the voltage; in that case we can utilize ToolBox the Surface Fitting Tool (cftool).

ISSN 2229-5518

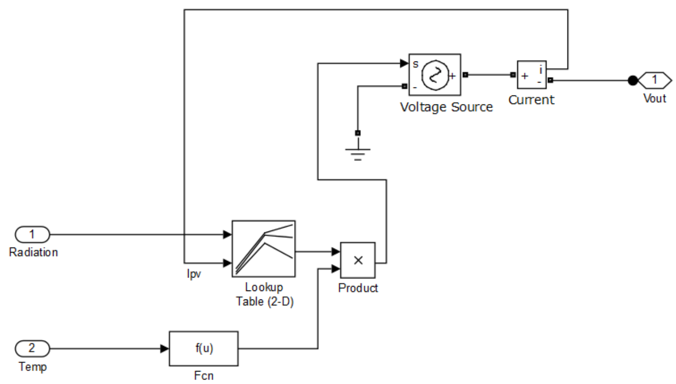

Fig.17. Building Simulink Blocks of a PV panel

IV. RESULTS

A. *The influence of solar radiation on the operation of a photovoltaic cell*

The following figure shows the current-voltage characteristic of a solar PV cell depending on the illumination at a constant temperature and velocity of the air. We note that the voltage corresponding to the maximum power varies slightly with the light, unlike the current, which increases sharply.

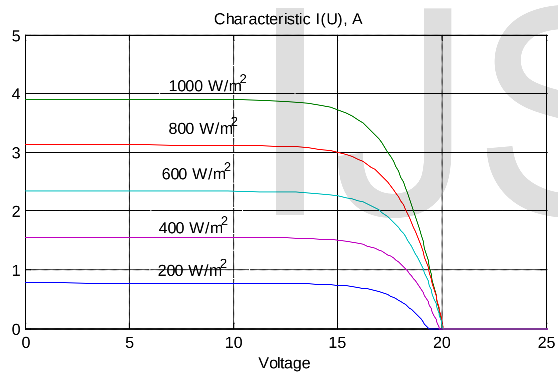

Fig.18. Characteristic *I = f (voltage)* for different illuminations

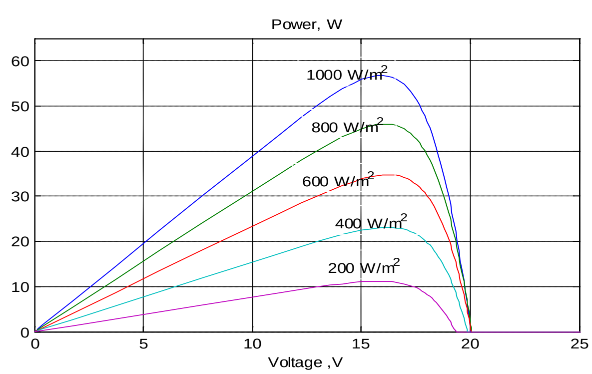

Fig.19. Characteristic *Power = f (voltage)* for different illuminations

B. *The influence of temperature on the operation of a PV cell*

The electrical characteristic of a PV cell depends on the temperature of the junction at exposed surface. The behavior of the PV cell based on the temperature is complex. The curves show the variation of current and voltage as a function of cell junction temperature. When the temperature increases, the voltage decreases as the current increases.

In case of silicon cells, the current increases about 0.025 mA / cm^2.°C, while the voltage decreases by 2.2 mV / ° C. The overall power reduction is about 0.4% per degree ° C. Thus, as the temperature increases the cell is less effective [11].

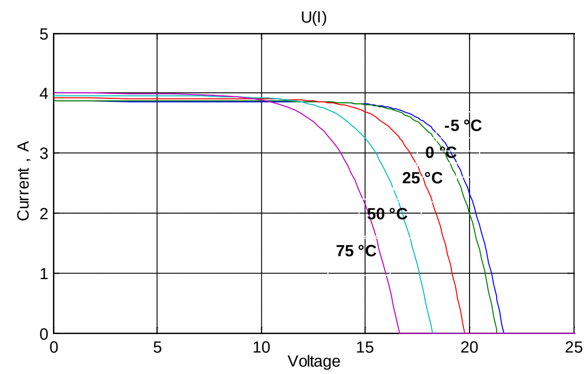

Fig.20. I (V) characteristic for different temperatures(1000 W/m^2)

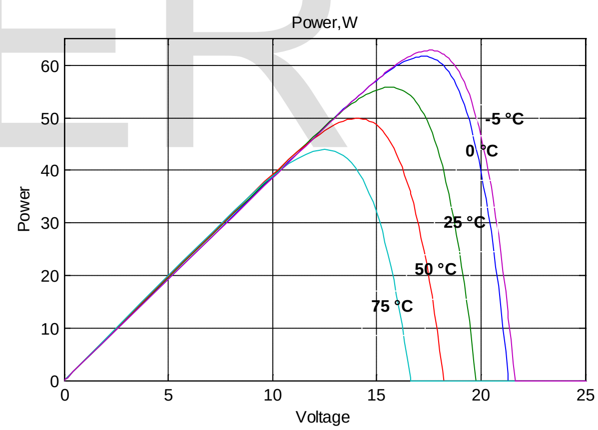

Fig.21. Power (V) characteristic for different temperatures (1000 W/m^2)

V. CONCLUSION

The aim of this work is to develop different models for a photovoltaic cell and mention some methods used in the literature to solve the equation $I_{pv}=f(U_{pv})$ under Matlab / Simulink and the Simscape / SimElectronics Toolbox .

REFERENCES

[1] Ludovic Protin, Stephan Astier, *Convertisseurs Photovoltaïques*, Technique de l'ingénieur, D3360.

[2] Andrew S. Golder, *Photovoltaic Generator Modeling for Large Scale Distribution System Studies*, Faculty of Drexel University Master of Science in Electrical Engineering, October 2006.

ISSN 2229-5518
[3] H.Tsai, C. Tu, and Y. Su, *Development of generalized photovoltaic model using MATLAB/SIMULINK* , Proceedings of the World Congress on Engineering and Computer Science 2008WCECS, October 22 - 24, 2008, San Francisco, USA.
[4] Kashif Ishaquea, Zainal Salama, Hamed Taheria
[5] Modeling and simulation of photovoltaic (PV) system during partial shading based on a two-diode model,http://dx.doi.org/10.1016/j.simpat.2011.04.005
[6] Gow, J.A. and C.D. Manning. *Development of a Photovoltaic Array Model for Use in Power-Electronics Simulation Studies*. IEE Proceedings of Electric Power Applications, Vol. 146, No. 2, pp. 193–200, March 1999.
[7] Geoff Walker, *Evaluating MPPT Converter Topologies Using a Matlab PV Model*, University of Queensland, Australia www.itee.uq.edu.au/~walkerg/publications/2000/pvmodel_00.pdf.
[8] A. Pierre Giroux, Gilbert Sybille, Hydro-Quebec Research Institute (IREQ) Carlos Osorio, Shripad Chandrachood , *The Mathworks Grid-ConnectedPV Array*.
[9] S. Rustemli, F. Dincer, *Modeling of Photovoltaic Panel and Examining Effects of Temperature in Matlab/Simulink*.Electronics and Electrical Engineering. Kaunas: Technologija, 2011. – No. 3(109). – P. 35–40.
[10] N. C. Sahoo, I. Elamvazuthi, Nursyarizal Mohd Nor, P. Sebastian and B. P. Lim,*PV Panel Modelling using Simscape ,IEEE*
[11] Djamila Rekioua,Ernest Matagne, *Optimization of Photovoltaic Power Systems Modélisation, Simulation and Control*. Springer, 5 janv. 2012 - 283 pages. http://books.google.dz
[12] Mukund R. Patel, PhD, *Wind and Solar Power Systems*, edition CRC PRESS
[13] Anca D. Hansen, Poul Sørensen, Lars H. Hansen and Henrik Bindner, *Models for a Stand-Alone PV System*, Risø National Laboratory, Roskilde December 2000.

NOTES: CHARACTERISTICS OF A SOLAR GENERATOR (MSX60)

Parameter	value
Maximum power	60 Watt
Voltage at point of maximum power	17.1V
maximum power current	3.55A
Short-circuit current	3.87A
Open circuit voltage.	21.1 V