The New Modeling for MPPT Control of Photovoltaic Cellules

M. Zandi, A. Payman, J-P. Martin, S. Pierfederici, B. Davat

Abstract -- Consideration of the Current-voltage (I-V) characteristics variations of solar modules with temperature and irradiations variations is basic for maximum power point tracking (MPPT). Having a simple and accurate mathematical model for the optimize utilization of the solar modules is essential. In this paper, a novel modeling of photovoltaic systems with novel coefficients is proposed for mathematical description of the current-voltage (I-V) characteristic. Based on the proposed novel temperature and irradiation coefficients, the mathematical modeling of the solar modules is accurate. The accuracy of this proposed model is evaluated through comparison of simulation results to the data provided by experimental tests. The variations of maximum power point parameters (MPPP) versus irradiation and temperature in the experimental tests and the proposed model is evaluated. The proposed model is as well as adaptable for MPPT control operation.

Index Terms - solar system modeling, temperature and irradiation coefficients, DC/DC converter, maximum power point tracking.

I. Introduction

The photovoltaic systems are one of the most important renewable energy sources since it has many advantages such as absence of fuel cost, clean without any environmental pollution, simple maintenance, inspective, etc [1-6]. Nowadays, it has various applications in the transporting systems, power stations, hybrid systems, households, portables systems, etc [4-9]. Therefore, knowledge of the photovoltaic systems electrical parameters behavior is essential for usage of its optimize. The traditional equivalent circuit of a solar cell represented by a current source in parallel with one diode is shown in Fig.1.

In this equivalent circuit, the photo source is for modeling the incident luminous flux. The diode parallel is for modeling the cell polarization phenomena. The two resistors (series and shunt) are for modeling the losses. The series resistance (R_s) represents the ohmic losses in the front surface of the cell and the shunt resistance (R_{sh}) represents the loss due to diode leakage currents [1, 2, 10, 11].

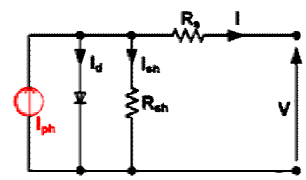


Fig.1 The equivalent circuit of the solar cell with one diode.

The basic operation of the photovoltaic systems is characterized by the I-V curve. This curve contains three important points: the open-circuit voltage (V_{oc}), the short-circuit current (I_{sc}) and maximum power point (MPP). In the MPP, photovoltaic systems can delivered maximum power (P_{max}) at MPP current (I_{max}) and MPP voltage (V_{max}). The photovoltaic systems depend on the weather conditions. The current-voltage (I-V) characteristics are varied both irradiation and temperature variations as shown in Fig. 2:

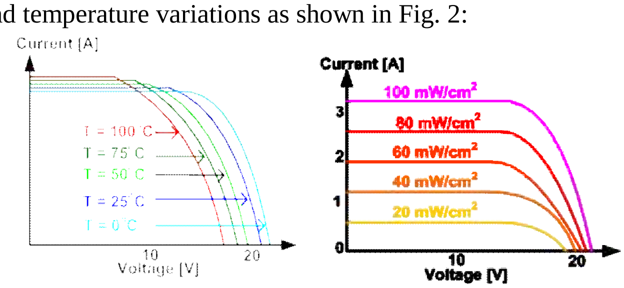


Fig.2- The I – V characteristic for various irradiations and temperatures.

Some mathematical formulations have been suggested in previous publications to model the solar cells [1, 2, 10 - 16]. In this paper, we propose novel mathematical formulation for solar cells. The proposed formulation considers both the effects of temperature and irradiation variations for more accuracy. This method is based on the specifications data provided at the current-voltage (I-V) characteristic in the standard test conditions (STC) and calculation the proposed

M.Zandi, A. Payman, J-P. Martin, S. Pierfederici, B. Davat,
Groupe de Recherche en Electronique et en Electrotechnique de Nancy (GREEN)Nancy Université – INPL avenue de la forêt de Haye, 54516 Vandoeuvre-lès-Nancy cedex- France Majid.Zandi@ensem.inpl-nancy.fr

novel formulations of:

- the temperature and irradiation coefficient on short- circuit current ΔI_{sc}
- the temperature and irradiation coefficient on open- circuit voltage ΔV_{oc}
- the temperature and irradiance coefficient on the voltage in maximum power point ΔV_{max}
- the open-circuit voltage of solar cell V_{oc}
- the voltage in the maximum power point (MPP) V_{max}

Experimental results are provided and validated the new formulations of these coefficients.

II. The Proposed Model Description

In the traditional equivalent circuit of a solar cell (Fig. 1), the value of flowed current (I_{sh}) in shunt resistance (R_{sh}) is very small. Therefore the I_{sh} current can be neglected in comparison to the diode current (I_d). Therefore the R_{sh} resistor can be neglected. Thus a simple equivalent circuit of a solar cell can be obtained with a current source in parallel with a diode, as shown in Fig.3

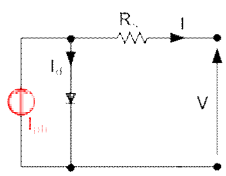


Fig.3 - The equivalent circuit of the solar cell with neglecting R_{sh}

The equation which describes the current-voltage (I-V) characteristic of equivalent circuit by neglecting the I_{sh} can be put into the following form [9, 10, 13, 14]:

$$I = I_{ph} - I_d = I_{ph} - I_o\left[e^{\frac{(V+IR_s)}{V_t}} - 1\right] \qquad (1)$$

Where V and I represent the output voltage and output current of the solar cell, respectively; R_s is the series resistance of the cell; I_{ph} is the light-generated current; I_d is the diode current; I_o is the reverse saturation current; V_t is the thermal voltage [10, 13, 14].

Considering the effects of irradiance and temperature on the photo current (I_{ph}), the photo current can be approximated as [10, 13, 14]:

$$I_{ph}(G_a,T) = I_{scs}\frac{G_a}{G_{as}}\left[1+\Delta I_{sc}(T-T_s)\right] \qquad (2)$$

where G_a and T represent irradiation and temperature respectively. Other parameters in eq. (2) are constants. I_{scs} is the short-circuit current on the standard test condition (STC); G_{as} is the standard irradiation (1000W/m2); ΔI_{sc} is the temperature and irradiance coefficient on the short-circuit current; and T_s is the standard temperature (298 ^oK).

To calculate the term I_{ph} in eq. (2), the temperature and irradiation coefficient, ΔI_{sc}, should be obtained. Although this coefficient is calculated and proposed by the others [14, 15, 16], a new formulation which leads to a better estimation of MPPT is suggested in this paper according to the eq. (3). More precisely, the proposed coefficient ΔI_{sc} is a function irradiation as well as temperature.

$$\Delta I_{sc} = \frac{\alpha}{I_{scs}}\left(\frac{G_{as}}{G_a} - 1\right) \qquad (3)$$

where α is the temperature coefficient on the short-circuit current and can be calculated as below.

$$\alpha = \frac{I_{sc}(T_1) - I_{sc}(T_2)}{(T_1 - T_2)} \qquad (4)$$

where I_{sc} (T_1) and I_{sc} (T_2) are short-circuit currents in T_1, T_2 temperatures at the same irradiations respectively. According to (1), the reverse saturation current in the open-circuit condition can be defined by:

$$I_o(G_a,T) = \frac{I_{ph}(G_a,T)}{e^{\left[\frac{V_{oc}(T)}{V_t(T)}\right]} - 1}$$
(5)

where V_{oc} is the open-circuit voltage. Some formulations are suggested in [10, 15, and 16]. Considering effect of the temperature and irradiation coefficient (ΔI_{sc}) on V_{oc} variations, a new formulation to the estimation of MMPT is proposed to calculate open-circuit voltage (V_{oc}) as:

$$V_{oc}(G_a,T) = V_{ocs} + \Delta V_{oc}\left|(T - T_s)\right| - R_s\Delta I_{sc}$$
(6)

where V_{ocs} is the open-circuit voltage on the standard test condition (STC). To calculate the term V_{oc} present in eq. (6), the temperature and irradiation coefficient ΔV_{oc} should be obtained. Although this coefficient is calculated and proposed by the authors in [16], a new formulation which leads to a better estimation of MPPP is suggested in this paper according to the eq. (7). More precisely, the proposed coefficient ΔV_{oc} is a function irradiation as well as temperature.

$$\Delta V_{oc} = \beta\left(\frac{G_{as}}{G_a} - 1\right)$$
(7)

β is the temperature coefficient which can be calculated as :

$$\beta = \frac{V_{oc}(T_1) - V_{oc}(T_2)}{(T_1 - T_2)}$$
(8)

where V_{oc} (T_1) and V_{oc} (T_2) are open-circuit voltages in T_1, T_2 temperatures at the same irradiations respectively.

The current amplitude I_{max} can be calculated from eq. (1) and eq. (7). It comes:

$$I_{max}(G_a,T) = I_{ph} - \left[\frac{e^{\left(\frac{V_{max}+I_{max}R_s}{V_t}\right)} - 1}{e^{\left(\frac{V_{oc}}{V_t}\right)} - 1}\right] I_{ph}$$
(9)

where V_{max} is the voltage in the maximum power point (MPP). Considering effect of the temperature and irradiation coefficient (ΔI_{sc}) on V_{max} variations, a new formulation is proposed to calculate this voltage in the maximum power point (V_{max}). We proposed:

$$V_{max}(G_a,T) = V_{maxs} + \Delta V_{max}\left|(T - T_s)\right| - R_s \Delta I_{sc}$$
(10)

where V_{maxs} is the voltage in the maximum power point (MPP) on the standard test condition (STC).
We propose to estimate the temperature and irradiation coefficient at the maximum power point noted ΔV_{max} thanks to the following relationship:

$$\Delta V_{max} = \gamma\left(\frac{G_{as}}{G_a} - 1\right)$$
(11)

γ is the temperature coefficient on the voltage in MPP conditions and can be calculated as below.

$$\gamma = \frac{V_{max}(T_1) - V_{max}(T_2)}{(T_1 - T_2)}$$
(12)

where $V_{max}(T_1)$ and $V_{max}(T_2)$ are voltages at MPP in T_1, T_2 temperatures at the same irradiations respectively. The series resistance can be calculated from eq. (1) and eq. (9).

$$R_s = \frac{V_t \ln\left[\left(1 - \frac{I_{max}}{I_{ph}}\right)e^{\left(\frac{V_{oc}}{V_t}\right)} + \frac{I_{max}}{I_{ph}}\right] - V_{max}}{I_{max}} \qquad (13)$$

III. The Simulation of the photovoltaic systems

Based on the equations (1 ~ 13) and determined parameters specifications in the STC, it is possible to formulate a simulation model of the solar module with Matlab Simulink. In fact, the model of the photovoltaic system is acquired by replacing the model of every cell in modules and panels by considering of link series and parallels [18]. The schematic diagram of solar cells connections in photovoltaic systems is shown in Fig. 4. I_{PV} and V_{PV} are the output current and output voltage of photovoltaic system respectively. N_S and N_P are number of the series and parallel branches of solar cells in photovoltaic system respectively.

The two Helios H1540 (typical 150W module) were chosen for experimental test and modeling. This module type has 40 solar cells. The outputs of the two modules were connected in series. The parameters specifications in the STC for two series modules are shown in table 1.

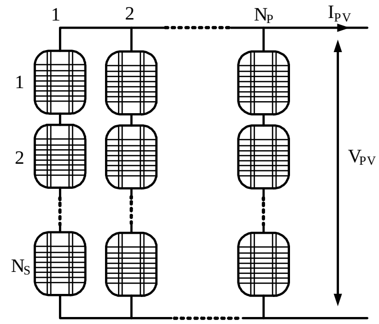


Fig.4 – Schematic diagram of solar cells in photovoltaic system by considering of link series and parallels.

parameter	symbol	value
Open-circuit voltage	V_{oc} (V)	46
Shot-circuit current	I_{sc} (A)	9.9
Voltage in the MPP	V_{max} (V)	35.6
Current in the MPP	I_{max} (A)	8.42
Maximum power	P_{max} (W)	300

Table 1- The parameters specifications in the STC for two series H1540 modules

Fig. 5 shows the modeling block diagram of the photovoltaic systems by the proposed model. This block diagram shows the relationship of the measured parameters (irradiation, temperature, short - circuit current, open - circuit voltage and maximum power point voltage in the various temperatures), standard conditions parameters (I_{scs}, V_{ocs}, I_{maxs} and V_{maxs}) and the calculated parameters. The current-voltage (I-V) characteristic of solar modules model by the proposed novel coefficients is shown in Fig. 6-a and Fig. 6-b. The Fig. 6-a shows the current-voltage (I-V) characteristics

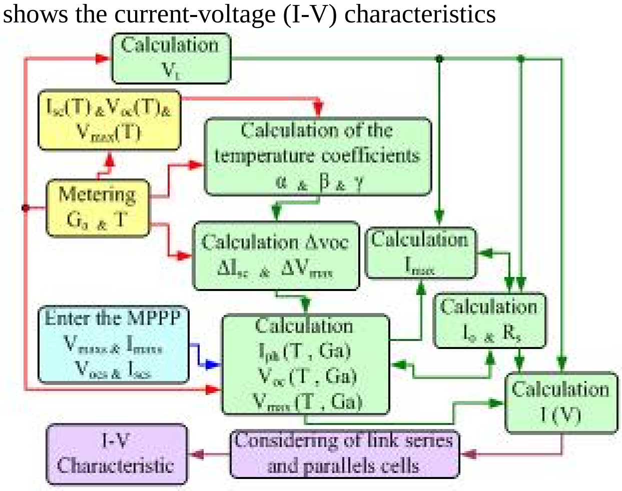


Fig.5- The modeling block diagram of the proposed model.

in various irradiations and constant temperature obtained from the proposed model by Matlab Simulink for two series H1540. Fig. 6-b shows the current-voltage (I-V) characteristics in various temperatures and constant irradiation obtained from the proposed model by Matlab Simulink for two series H1540.

Fig.6-a shows with the higher irradiation level, both voltage and current increases. Fig.6-b shows with higher temperature level, voltage decreases but current is increased very slightly. There are logic results for the solar modules.

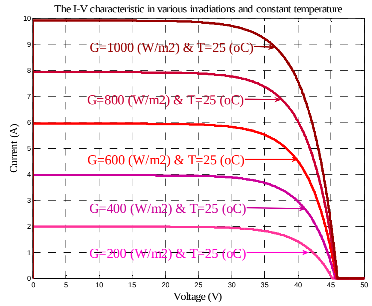


Fig.6-a- The I – V characteristic for various irradiations and fixed temperature obtained with proposed model.

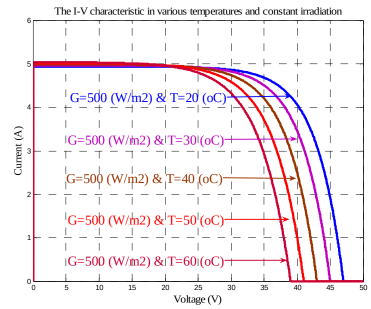


Fig.6-b- The I – V characteristic for various temperatures and fixed irradiation obtained with proposed model.

IV. Comparison of experimental and modeling results

The experimental results are obtained from test system as shows in Fig. 7. This test system consists of five essential parts. The experimental bench consists of two series H1540 Helios modules, irradiation meter for sensing and metering the irradiation in the test time, dynamic load for changing the value of output current and voltage, two types of thermometer for sensing the temperature variations and oscilloscope for metering the parameters.

Fig. 8 shows the obtained Current-voltage (I-V) characteristics of the experimental tests from test system in constant temperature (T=25^{o}C) and various irradiations (G= 100 - 300 W/m^2).

The tests were carried out in the mornings of September and out-door. Fig. 9 shows the I-V characteristics of the proposed model by Matlab Simulink in the same condition (T=25 ^{o}C & G= 100 - 300 W/m^2).

From comparison between Fig. 8 and Fig. 9, it can be seen that:

a) The open-circuit voltage (V_{oc}) of the current-voltage (I-V) characteristic in the proposed model and experimental tests are the same. The novel proposed coefficients (β, ΔV_{oc}, γ and ΔV_{max}) are accurate.

b) The short-circuit current (I_{sc}) of the current-voltage (I-V) characteristic in the proposed model and experimental tests are the same. The novel proposed coefficients (α and ΔI_{sc}) are accurate.

c) Nevertheless the slop of the current-voltage (I-V) characteristic from experimental tests is more abrupt than the current-voltage (I-V) characteristic obtained with the Matlab/Simulink model. The neglecting of some parameters in the equivalent circuit draw on this difference.

Fig.7-The test system for experimental results.

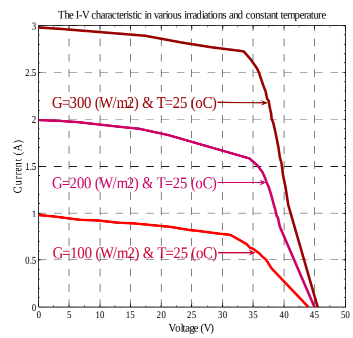


Fig.8 - The I – V characteristic obtained from experimental test

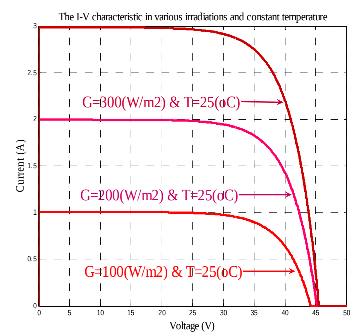


Fig. 9 - The I – V characteristic obtained with proposed model

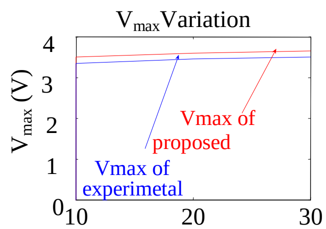
A comparison of the parameters in the MPP conditions (I_{max}, V_{max} and P_{max}) between the proposed model and experimental tests is carried out. Accuracy of these parameters is important for accuracy of the MPPT control methods. In Fig. 10 and Fig. 11, it can be shown accuracy of the parameters in MPP conditions. Fig. 10 allows investigating the variations of MPP parameters as a function of the irradiation at constant temperature.

The Fig. 10(a), Fig. 10(b) and Fig. 10(c) show:

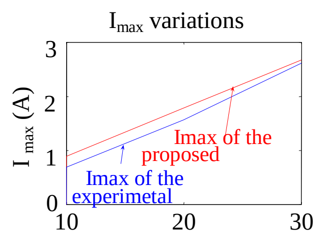
- the variations slop of maximum power point parameters (MPPP) in the proposed model and experimental tests are the same;
- the values of the maximum power point parameters (MPPP) in the proposed model are approximated these values in the experimental tests;

- the variations slop of V_{max} for fixed temperature and various irradiations is very gradual;
- the variations slop of I_{max} for fixed temperature and various irradiations is steep;
- the variations slop of P_{max} for fixed temperature and various irradiations is steep as if I_{max};

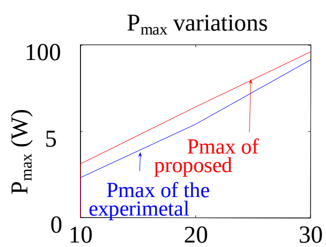
From previous results, there is showed that the proposed model in various temperatures or irradiations conditions can be used for MPPT control operation.



(a) - Irradiation (W/m2)



(b) - Irradiation (W/m2)



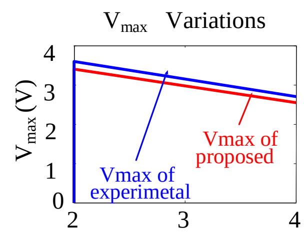
(c) - Irradiation (W/m2)

Fig.10- variations comparison of MPPP at the constant temperature and various irradiation in proposed model and experimental tests; (a) variations of V_{max}, (b) variations of I_{max}, (c) variations of P_{max}

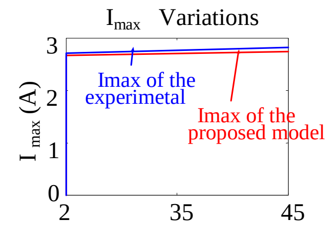
Fig. 11 shows the variations comparison of MPP parameters versus temperature at constant irradiation in the experimental tests and the proposed model. From Fig. 11(a), Fig. 11(b) and Fig. 11(c) perceive:

- the variations slop of maximum power point parameters (MPPP) in the proposed model and experimental tests are the same;
- the values of the maximum power point parameters (MPPP) in the proposed model are approximated these values in the experimental tests;
- the variations slop of V_{max} for fixed irradiation and various temperatures is steep;
- the variations slop of I_{max} for fixed irradiation and various temperatures is very gradual;
- the variations slop of P_{max} for fixed irradiation and various temperatures is steep as if V_{max};

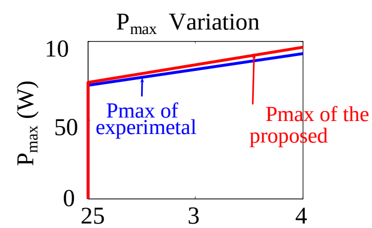
From above results, there is demonstrated that the proposed model in various temperatures is adaptable for maximum power point tracking (MPPT) control operation.



(a) Tempetrature (oC)



(b) Temperature (oC)



(c) Temperature (oC)

Fig.11- variations comparison of MPPP at the constant irradiation and various temperature in proposed model and experimental tests; (a) variations of V_{max}, (b) variations of I_{max}, (c) variations of P_{max}

V. Maximum power point tracking (MPPT) with the proposed model

The schematic diagram of maximum power point tracking (MPPT) control system with the proposed model is depicted in Fig. 12. The solar module trough boost converter connects to the battery bank. In this schematic diagram is used the MPPT Controller Unit for calculation the current in the maximum power point (I_{max}) and output voltage of solar module (V) from proposed model. The measured irradiation (G) and temperature (T) are input of the proposed model and arrive into MPPT Controller Unit. The output from MPPT Controller Unit (I_{max}) can be compared with the output current of solar module (I) in the Sliding Mode Controller Unit and will be create the PWM signal for adjusting the duty cycle of the boost converter. Therefore, with the proposed model can de tracked maximum power point without utilize voltage measurement in the output of solar model.

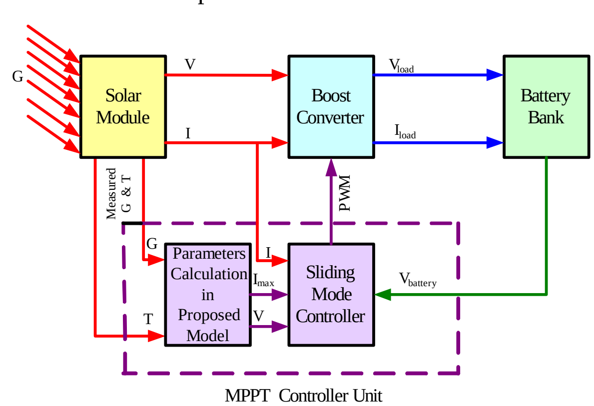


Fig.12- The schematic diagram of MPPP with the proposed model

Fig. 13 and Fig.14 show the solar module current (I_{ps}) variations and the current in the MPP (I_{max}) and the load power (P_{load}) variations and the maximum power (P_{max}) variation versus different times in various temperatures and various irradiations respectively. For these results, temperature is varied from 300 (^oK) to 330 (^oK) and irradiation is varied from 300 (W/m^2) to 800 (W/m^2).

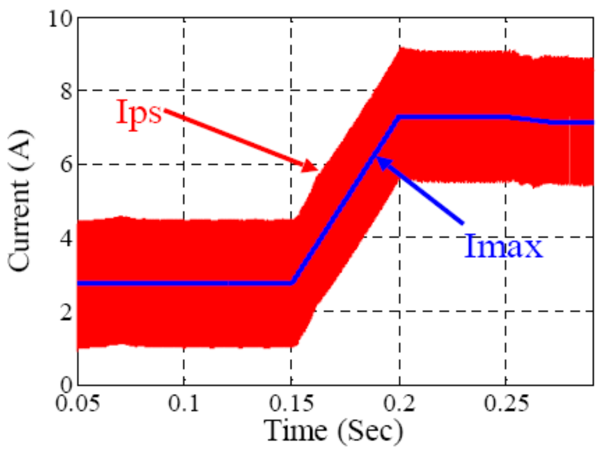


Fig.13- The curves of current in the MPP (I_{max}) and load current (I_{load})

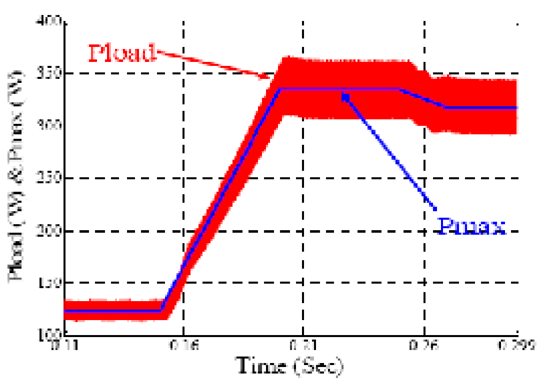


Fig.14- The curves of maximum power (P_{max})

The curves of temperature variations and irradiation variations versus different times show in Fig. 15.

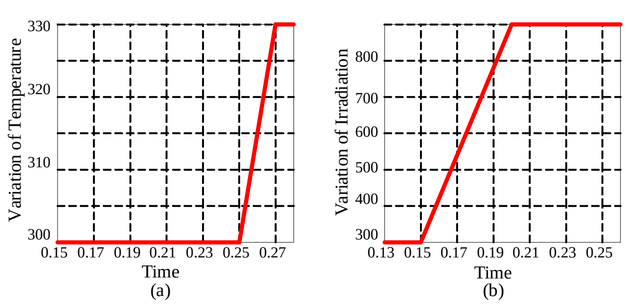


Fig.15- The curves of various temperatures and various irradiations

VI. Conclusions

In this paper, new analytical expressions of key parameters of a classical solar panel model have been proposed to take into account the variations of temperature and irradiation. Experimental results have validated the results obtained by simulations. Thanks to the proposed model, it is possible, if we measure the temperature and the irradiation, to know precisely the MPP parameters and thus eliminate the maximum power point tracking (MPPT) issue.

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