

Theoretical and Experimental Studies of Electrical Parameters: Irradiance G and Temperature T Effects

SORY Mamadou Osias

Units of Sciences and Technology, Department of Physic
Nazi Boni University, Bobo Dioulasso, Burkina Faso
Units of Sciences and Technology, Department of Physic
Laboratory of Materials, Heliophysic and Environment
Nazi Boni University, Bobo Dioulasso, Burkina Faso

SAM Raguilignaba

Units of Sciences and Technology, Department of Physic
Nazi Boni University, Bobo Dioulasso, Burkina Faso
Units of Sciences and Technology, Department of Physic
Laboratory of Materials, Heliophysic and Environment
Nazi Boni University, Bobo Dioulasso, Burkina Faso

DIASSO Alain

Units of Sciences and Technology
Department of physic, Laboratory of Materials and Environment
Joseph Ki-Zerbo University, Ouagadougou, Burkina Faso

ABSTRACT

The present work explores the effects of temperature T and irradiance G on electrical parameters as serie resistance, fill factor and conversion efficiency within the base region of p-n junction of a polycrystalline solar cell. This work is conducted in two forms as a theoretical study and an experimental study. Indeed, the solar cell is submitted firstly to various temperature and secondly to various irradiance values. From a theoretical approach based on the single exponential model theory, the I-V equation expression is established. This expression taking account implicitly G and T. This equation I-V permits to develop Matlab script to calculate I-V and P-V values versus T and G. The series resistance, fill factor and conversion efficiency values versus T and G are then deducted and analyzed. From a simple experimental setup permitting I-V values measurements, the experimental values of serie resistance, fill factor and conversion efficiency are calculated and also analyzed. First, these theoretical and experimental results are in good agreement and secondly are in good agreement with those of the literature.

Keywords: Conversion efficiency, Fill factor, Irradiance, Serie resistance, Temperature.

INTRODUCTION

Nowdays, climate change explain temperature peak and solar irradiance variation sometimes observed. In these conditions, solar cell quality is affected. This quality is depended precisely of

electrical parameters as series resistance, fill factor and conversion efficiency ... Then, solar cell optimization operating is controlled by these parameters.

In this study, we are interested to determinate temperature T and irradiance G effects on series resistance, fill factor and conversion efficiency from theoretical approach and experimental approach.

Firstly, the theoretical study mainly using a single exponential model theory permit I-V equation expression establishment. From this expression, Matlab script is built to calculate I-V and P-V values. Series resistance, fill factor and conversion efficiency values are then deducted. Secondly, from a simple experimental set-up; after registration and conversion of I-V curves to numerical data, the values of series resistance, fill factor and conversion efficiency are calculated versus T and G.

Thirdly, the effects of T and G on series resistance, fill factor and conversion efficiency reported and analyzed from theoretical and experimental results obtained.

MATERIALS

The list of experimental set-up materials is as follows:

- a mono-facial silicon solar cell named GES- 13001
- a halogen lamp to simulate the sun light near AM1.5
- a numerical multimeters DMM1 and DMM2
- a GES-18002 solarimeter
- a GES- 18003 aquisition set-up
- a MWD-1501000E transformer
- an etuve
- a computer

The experimental set-up is presented on figure 1

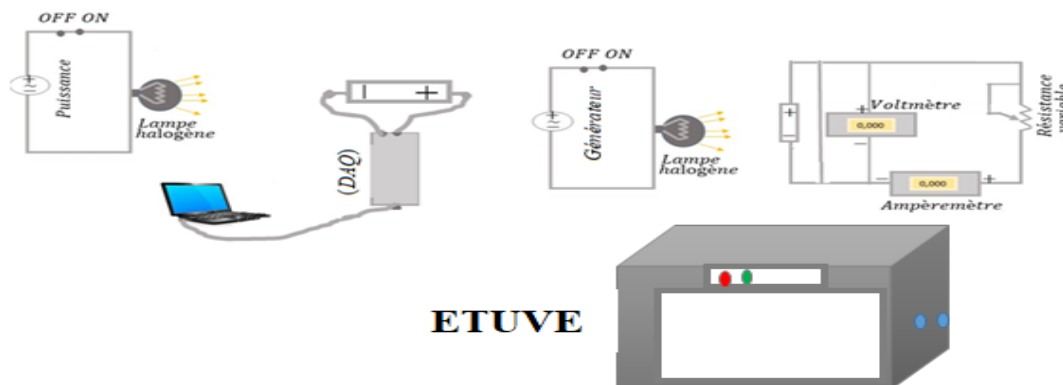


Figure 1 : Experimental set-up

Matlab 2013a and Microsoft Excell 2016 software are use respectively to calculate data and to plot curves. Matlab 2013a is MATLAB and Simulink product. New in this release is the introduction of Fixed-Point Designer, which combines the functionality of Fixed-Point Toolbox and Simulink Fixed Point. Excel 2016 is a version of Excel developed by Microsoft that runs on the Windows platform.

THEORETICAL APPROACH

We consider a mono facial polycrystalline solar cell operating under a various values of T and G and illuminated under AM1.5 spectrum lighth.

The equivalent circuit of one exponential model illustrated on figure 2.

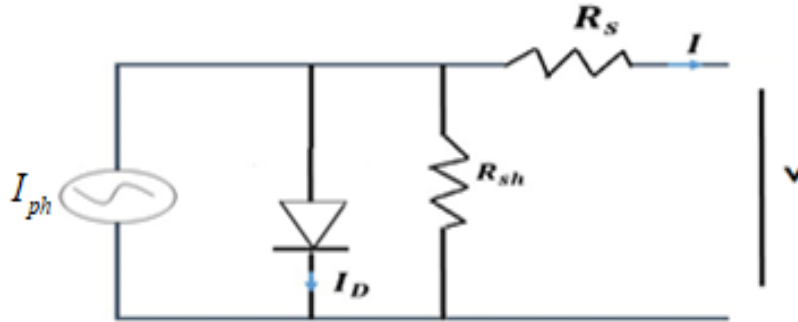


Figure 2 : A solar equivalent model circuit

When solar cell is illuminated, the expression of current I is giving by equation 1 [1, 2]

$$I = I_{ph} - I_s \left(e^{\frac{q(V+R_s I)}{nkT}} - 1 \right) - \frac{V + R_s I}{R_{sh}} \quad (1)$$

I is solar cell current

I_{ph} is proportionnal to irradiance G. Its expression is follow as:

$$I_{ph} = \left(\frac{G}{G_0} \right) I_{cc} \quad (2)$$

Where :

$$I_{cc} = I_{cc,ref} \left[1 + a(T - T_{ref}) \right] \quad (3)$$

- I_{cc} is short circuit current at temperature T
- $I_{cc,ref}$ is short circuit courant when irradiance $G_0 = 1000 W.m^{-2}$ and $T = T_{ref} = 25$ Celsius degrees
- a is temperature change coefficient in $\frac{\%}{^\circ C}$ indicated on technical sheet.

G_0 is standard irradiance value for solar cell performance quantification [3]

I_D is polarisation current giving by equation 4.

$$I_D = I_s \left(e^{\frac{q(V+R_s I)}{nkT}} - 1 \right) \quad (4)$$

- R_s is serie resistance and it impacted the slop of I-V curves near open circuit [4]. By derivating open circuit voltage expression, we get R_s expression and after simplification [5]

$$R_s = \frac{dV}{dI} \bigg|_{V_{oc}} - \frac{1}{\chi_v} \quad (5)$$

and

$$\chi_v = \frac{qI_{s,ref}}{nkT} e^{\frac{qV_{co}}{nkT}} \quad (6)$$

Where $\frac{dV}{dI} \bigg|_{V_{oc}}$ is I-V characteristic slop near open circuit conditions [6].

- I_d diod inverse saturation current [6].

$$I_s = I_{s,ref} \left(\frac{T}{T_{ref}} \right)^{\frac{3}{n}} \cdot e^{\frac{q}{nk} \left(\frac{1}{T_{ref}} - \frac{1}{T} \right)} \quad (7)$$

where $I_{s,ref}$ is diod inverse saturation current at temperatutre T_{ref} and its expression is given by the equation 8[7].

$$I_{s,ref} = \frac{I_{cc}}{\left(e^{\frac{qV_{co}}{nkT_{ref}}} - 1 \right)} \quad (8)$$

- q indicates electron charge
- k Boltzmann constante value
- V is solar cell voltage
- n diod ideality factor for polycrystalline silicon $n=1.62$
- R_{sh} is shunt resistance

For the rest, we consider shunt resistance infinitely large, so it impact can be neglected and it cannot be taking to account \cite{MM, A, d}. The equation 1 becomes:

$$I = I_{ph} - I_s \left(e^{\frac{q(V+R_s I)}{nkT}} - 1 \right) \quad (9)$$

Moreover, we calculate electrical parameters expression from the single exponential model theory and the I-V and P-V characteristic.

From the maximal peak power point, the fill factor FF and the efficiency conversion η expression are found\cite{R, N} respectively:

$$FF = \frac{V_m \cdot I_m}{V_{co} \cdot I_{cc}} \quad (10)$$

$$\eta = \frac{V_{co} \cdot I_{cc} \cdot FF}{P_{inc}} \quad (11)$$

Series resistance expression is calculated from I-V characteristic and the following approximation:

$$e^{\frac{(V_1 + R_s I_1)}{V_T}} \gg 1 \quad (12)$$

By considering two points of I-V characteristic (I_1, V_1) and (I_2, V_2) , we obtain the equation 13:

$$\begin{cases} I_{ph} - I_1 = I_s \cdot e^{\frac{q(V_1 + R_s I_1)}{V_T}} \\ I_{ph} - I_2 = I_s \cdot e^{\frac{q(V_2 + R_s I_2)}{V_T}} \end{cases} \quad (13)$$

So

$$R_s = \frac{V_T}{I_2 - I_1} \cdot \ln \left(\frac{I_{ph} - I_2}{I_{ph} - I_1} \right) - \frac{V_2 - V_1}{I_2 - I_1} \quad (14)$$

Mathematical formulation permit to obtain the following organigram:

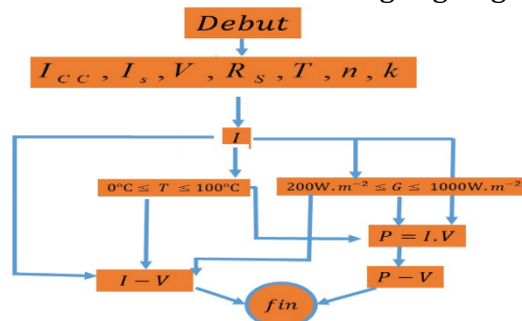


Figure 3: I (V) and P(V) simulation organigram

EXPERIMENTAL APPROACH

In the experimental setup, a solar cell is associate to a numerical multimeters DMM1 and DMM2. This multimeter can measure solar cell voltage, the delivered current and the peak power point variation using variable charge R. The solar cell is illuminated by a reglable power halogen lamp and irradiance is measured by a solarimeter. This equipment is placed in an etuve. By varying the value of charge R of the multimeter DMM1 and DMM2 from its minimum value to its maximum value, the different operating points are obtained. These points permit to plot I-V or P-V characteristic for different values of G and T.

RESULTS AND DISCUSSIONS

Theoretical results and discussions

Theoretical results obtained are analyzed and the effects of irradiance and temperature are deducted.

Temperature effects on electrical parameters

The effects of temperature on electrical parameters are reported. The effects of T on I-V and P-V characteristics are illustrated respectively on figure 4 and 5.

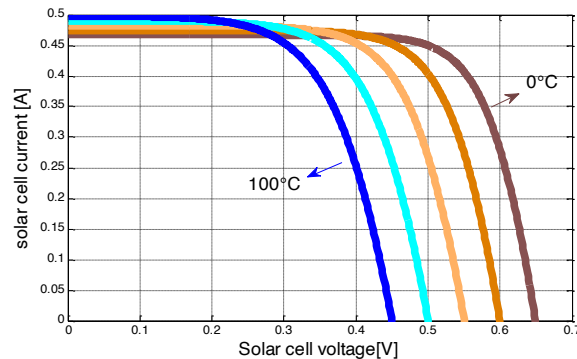


Figure 4 : Temperature effects on I-V characteristic

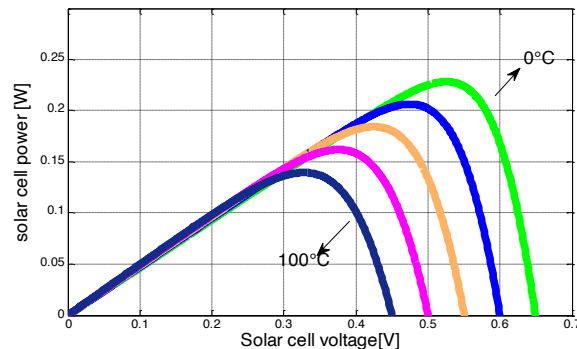


Figure 5 : Temperature effects on P-V characteristic

The effects of temperature on serie resistance, fill factor and conversion efficiency are enregistered on table 1. The values of these parameters are calculated from I-V and P-V characteristics and equation 10, 11, 14.

Table 1 : Effects of temperature on electrical parameters

$T(^{\circ}\text{C})$	0	25	50	75	100
I_1	0.1	0.1	0.1	0.1	0.1
I_2	0.05	0.05	0.05	0.05	0.05
V_1	0.635	0.585	0.540	0.490	0.435
V_2	0.645	0.595	0.550	0.497	0.440
Efficiency cpnversion $\eta(\%)$	19.17	17.5	15.00	14.17	11.67
Fill factor $FF(\%)$	75.42	73.68	70.88	64.66	61.79
$Rs(m\Omega)$	3.72	3.72	3.99	4.11	4.28

After observation of these table and figures, we remark:

- Firstly, a weak increase ($\approx 6\%$) of short current when T increase.
- Secondly, a strong decay of open circuit voltage and a decrease of peak power when T increase from 0°C to 100°C
- Thirdly, a weak increase of serie resistance and a decay of fill factor and conversion efficiency when T increase

This absurdity on the behaviour of short circuit current traduce an increase of charge carriers loss to the jonction. Also, the increase of serie resistance is explained by a weak increase of charge carriers loss to solar cell interfaces.

Irradiance effects on electrical parameters

The effects of irradiance on electrical parameters are reported here. The effects of G on I-V and P-V characteristics are represented respectively on figure 6 and 7.

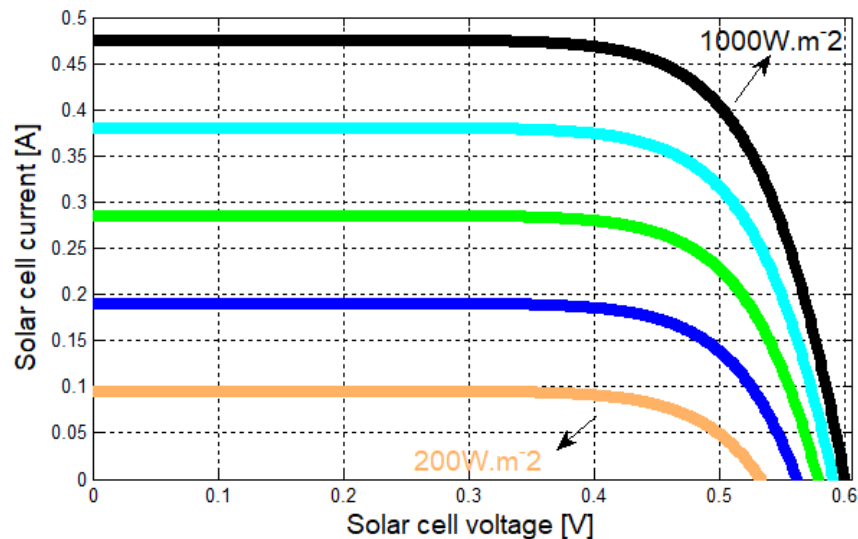


Figure 6 : Irradiance effects on I-V characteristic

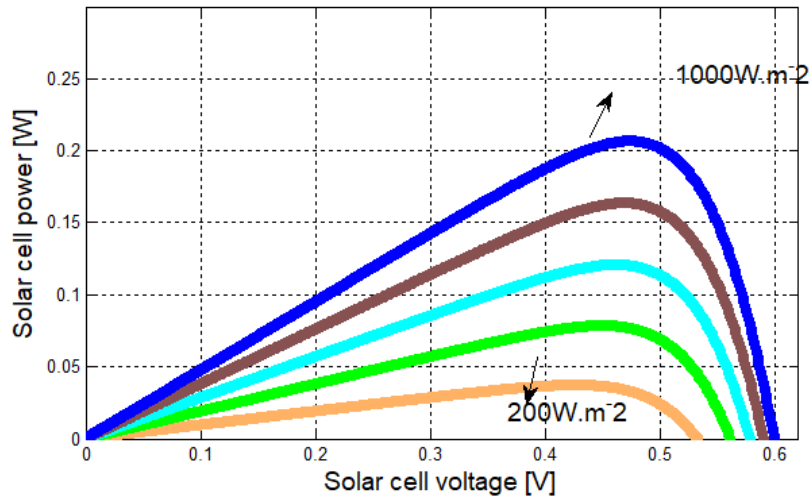


Figure 7 : Irradiance effects on P-V characteristic

The irradiance effects on series resistance, fill factor and conversion efficiency are noted on table 2. The values of these parameters are calculated from I-V and P-V characteristics equation 10, 11, 14.

Table 2 : Effects of irradiance on electrical parameters

<i>Irradiance $G(W.m^{-2})$</i>	1000	800	600	400
I_1	0.1	0.1	0.1	0.1
I_2	0.05	0.05	0.05	0.05
V_1	0.580	0.570	0.555	0.528
V_2	0.595	0.585	0.570	0.550
<i>Efficiency conversion $\eta(\%)$</i>	17.50	17.19	16.92	16.46
<i>Fill factor $FF(\%)$</i>	73.68	72.99	72.55	71.97
$R_s(m\Omega)$	0.91	4.97	6.90	12.46

The observations of I-V and P-V graphs and table 2 show:

- Firstly a strong increase of short circuit current when G increase.
- Secondly a weak decay of open circuit voltage and a decay of peak power when G decrease
- Thirdly, a peak decay of series resistance (from $12.96m\Omega$ to $0.91m\Omega$) and a decay of fill factor and conversion efficiency when G decrease from $400W/m^2$ to $1000W/m^2$

The strong increase of short circuit current jointly with a weak increase of open circuit voltage explain a weak reduction of charge carriers loss to the junction. Moreover, a strong increase of series resistance report a weak of charge carriers loss to interfaces.

Experimental results and discussions

In this section, the experimental results are presented. From experimental data I-V and P-V characteristics are plotted from 25°C to 65°C. The electrical parameters as series resistance, fill factor and conversion efficiency are deducted and analyzed.

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Effects of temperature on electrical parameters

The effects of temperature on electrical parameters are reported. The effects of T on I-V and P-V characteristics are represented respectively on figure 8 and 9.

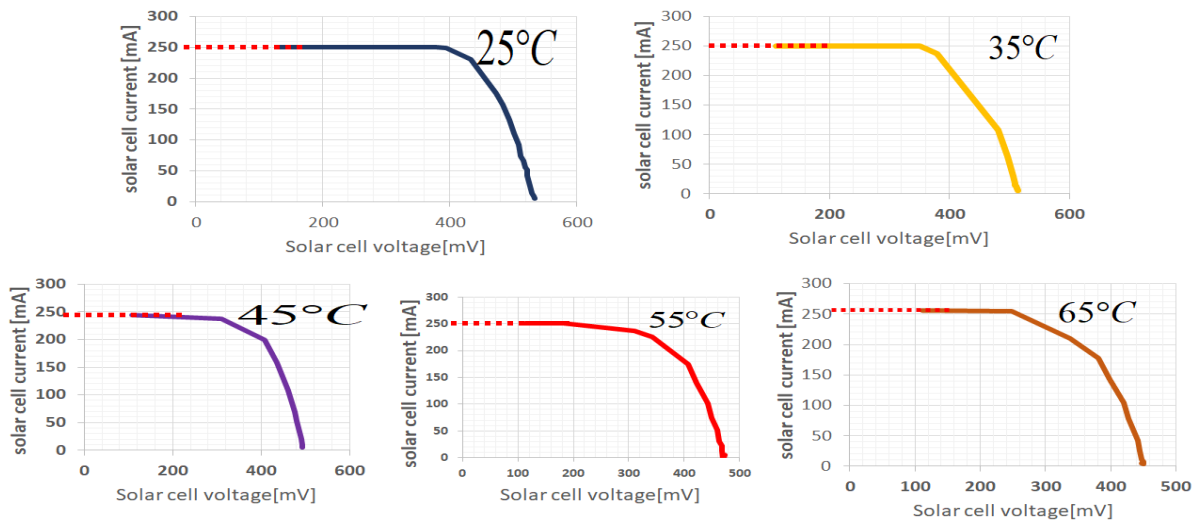


Figure 8 : Effects of temperature on I-V characteristic

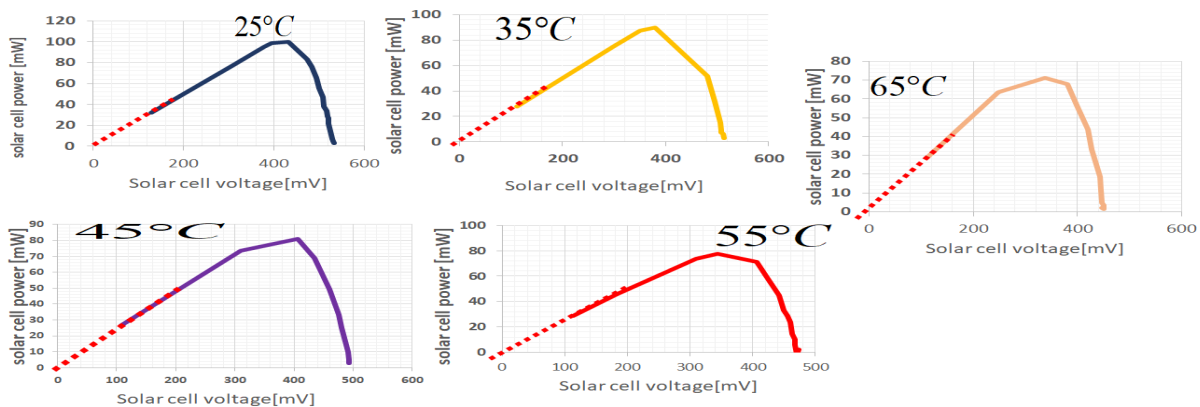


Figure 9: Effects of temperature on I-V characteristic

The effects of temperature on series resistance, fill factor and conversion efficiency are enregistered on table 3. The values of this parameters are calculated from I-V and P-V characteristics and equation 10, 11, 14.

Table 3 : Effects of temperature on electrical parameters

Temperature(°C)	25	35	45	55	65
I_1	0.06	0.06	0.06	0.06	0.06
I_2	0.02	0.02	0.02	0.02	0.02
V_1	0.525	0.495	0.475	0.450	0.430
V_2	0.535	0.515	0.490	0.470	0.455
Efficiency conversion $\eta(\%)$	6.39	6.24	5.63	5.38	4.94
Fill factor $FF(\%)$	71.24	69.88	67.07	65.22	62.09
$R_s(m\Omega)$	0.59	0.72	0.81	1.02	1.22

After observation of these table and figures, we have:

- an open circuit voltage decay with temperature increase
- a short circuit current weak increase and a peak power decrease with temperature decrease
- a series resistance weak increase, fill factor and series resistance decrease with temperature increase

The decay of open circuit voltage jointly with short circuit increase explain charge carriers loss to the junction. The series resistance increase explain a charge carriers weak increase to interfaces.

Effects of irradiance on electrical parameters

Irradiance effects on electrical parameters are outlined. The effects of G on I -V and P-V characteristics are represented respectively on figure 10 and 11. The operating points I-V and P-V are obtained from $1000W/m^2$ to $250W/m^2$ and electrical parameters are computed from the plage of irradiance values.

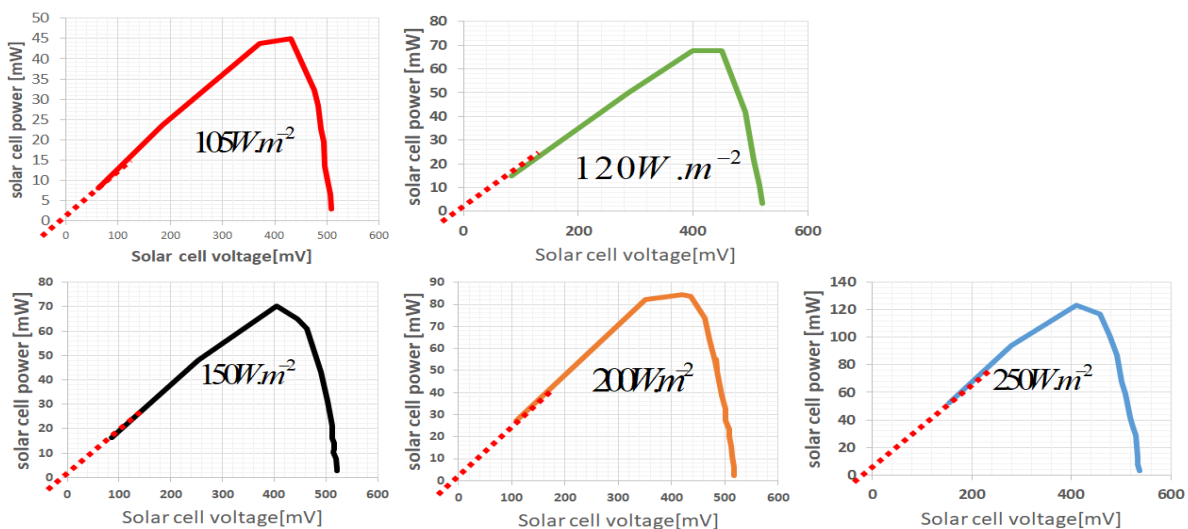


Figure 10 : Effects of irradiance on I -V characteristic

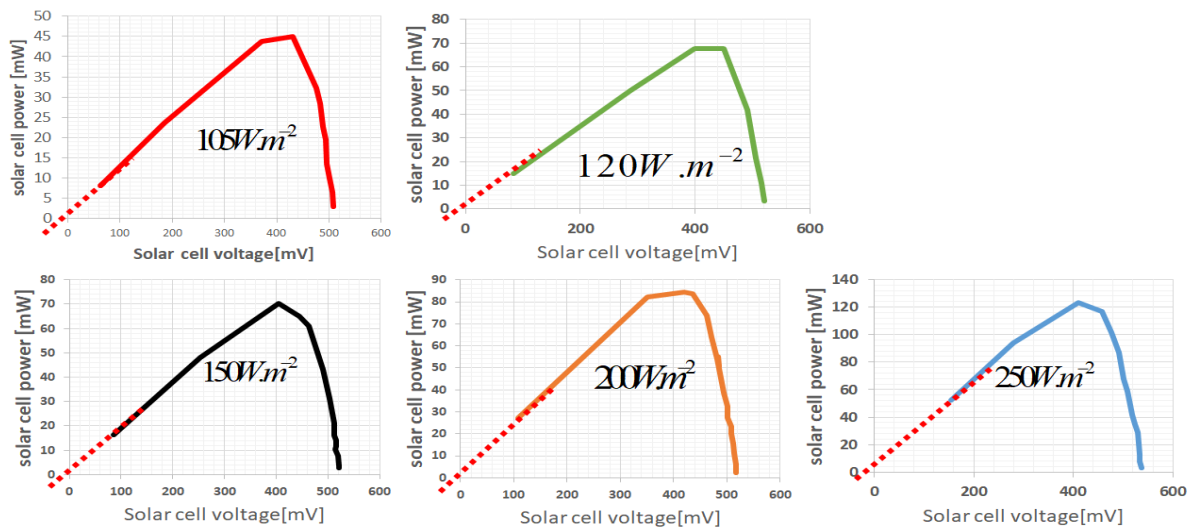


Figure 11 : Effects of irradiance on P- V characteristic

The following curves show the effects of irradiance on P-V characteristic. The effects of irradiance on series resistance, fill factor and conversion efficiency are noted on table 4.

The values of this are calculated from I-V and P- V characteristics and equation 10, 11, 14. The I-V and P-V experimental curves present the same form that theoretical I- V and P- V curves. The variation of series resistance, fill factor and conversion efficiency are also the same that those observed theoretically.

Table 4 : Effects of irradiance on electrical parameters

Irradiance ($W.m^{-2}$)	250	200	150	120	100
I_1	0.06	0.06	0.06	0.06	0.06
I_2	0.02	0.02	0.02	0.02	0.02
V_1	0.520	0.515	0.505	0.500	480
V_2	0.535	0.530	520	0.518	0.500
Efficiency conversion $\eta(\%)$	7.29	7.22	6.77	6.74	6.24
Fill factor $FF(\%)$	64.33	65.43	71.25	72.23	78.36
$R_s(m\Omega)$	0.74	0.80	0.89	1.02	1.27

By observing the values of table4 and the figures 10 and 11; we make the following analysis:

- a weak decay of open circuit voltage when irradiance decrease
- a decrease of solar cell peak power when irradiance decrease
- a increase of short circuit current if irradiance increase, the peak power point value increase also with the increase of irradiance.
- a series resistance and fill factor increase against efficiency conversion decay with irradiance decrease.

Globally; the I-V and P-V experimental curves present the same form that theoretical I-V and P-V curves. The variation of series resistance, fill factor and conversion efficiency are also the same that those observed theoretically.

The reduction of short circuit current intensity traduce the decay of charge carriers through the junction. Also, an increase of series resistance report a weak of charge carriers loss to grain interfaces. Theses variations explain the decay of fill factors and efficiency conversion.

CONCLUSION

In this paper, theoretical study and experimental study of temperature and irradiance effects on three electrical parameters as series resistance, fill factor and conversion efficiency of silicon solar cell are conducted.

Firstly, from the single exponential electrical model approximation, I-V and P-V points are calculated from Matlab script based on NEWTON-RAPHSON algorithm. The expressions of series resistance, fill factor and conversion efficiency are then established and calculated.

Secondly, from a simple experimental setup permitting the measure of I-V and P-V points, experimental values of series resistance, fill factor and conversion efficiency are found.

The experimental results show that electrical parameters variations versus G and T are conform that those observed theoretically.

These variations explain that the increase of temperature create charge carriers loss to interfaces and junction. However the increase of irradiance reduce these loss of charge carriers.

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