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Impact of External Electric Field on the Performance Parameters of PV Solar Cells under High Light Concentration

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The performance of a photovoltaic solar cell depends on a number of external and internal factors. It then appears imperative that investigations be carried out to identify the factors favourable or unfavourable to the proper operation of the photovoltaic cell. It is in this context that we study the influence of an external variable electric field on the electric parameters of a photovoltaic solar cell under light concentration of 50 suns. After the presentation of the model of a photovoltaic solar cell used in our study and formulated the assumptions, we have established the expressions of electric

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parameters as function of the external electric field E_0. Then, by using numerical simulation with MATCAD software, we plotted the curves of electric parameters versus the external electric field. From analysis of the curves, it appears that the short-circuit photocurrent density, electric power, fill factor and conversion efficiency increases with the increase in the intensity of the external electric field. On the other hand, it appears a drop in open circuit photovoltage and series resistance with the increase in the intensity of the external electric field.

Keywords: Electric strength; electric power delivered; series resistance; conversion efficiency.

1. INTRODUCTION

Today, many researchers are investing in the field of photovoltaic solar energy with the aim of increasing the performance of photovoltaic cells and reducing their manufacturing cost. Improving or degradation of the performances of a photovoltaic cell can also depend on the operating conditions. Indeed, studies have shown that intense illumination improves the performances of photovoltaic cell [1,2] while magnetic field lead to decrease of theirs performances [3,4]. Other studies has shown that high temperature damaged the performances of photovoltaic cells [1,5], an electric field improve theirs performances [6,7], and that protons irradiation lead to the damage in those same performances [8]. Works carried out on concentration photovoltaic cell show that theirs conversion efficiencies are better than those of ordinaries photovoltaic cells (up to 47.1% in laboratory) [9]. Moreover, the multiplicity of electric field sources in our environment (TV antenna, BTS, etc) influence the behaviour of photovoltaic cells during theirs operating mode. It is then important for us to take a look at the influence of an external electric field on the performances of a photovoltaic solar cell under intense illumination. This study will increase our understanding of the behaviour of the photovoltaic cell under intense illumination of 50 suns and in the presence of a variable external electric field.

2. MATHEMATICAL MODELING AND ASSUMPTION

The photovoltaic solar cell used for this study is presented on the Fig. 1 below:

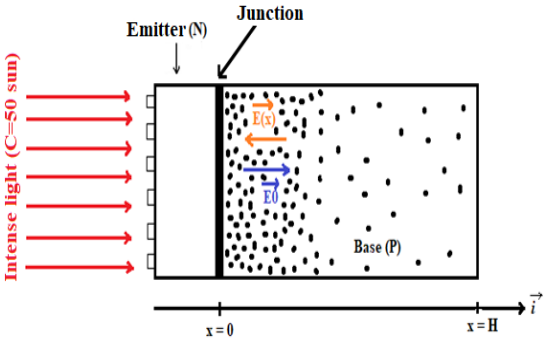

Fig. 1. Photovoltaic cell under concentrated illumination and under external electrical field

The solar photovoltaic cell is submitted to a concentrated light of 50 suns. Moreover, this photovoltaic cell is under an external variable electric field $\overrightarrow{E_0}$. The electric field E_0 is assumed to be uniform in the bulk of the base. Taking into account the mode of illumination of the photovoltaic solar cell, we also take into account the electric field induced by the concentration gradient $\overrightarrow{E(x)}$ given by the equation below [10]:

$$E(x) = \frac{D_p - D_n}{\mu_n + \mu_p} \cdot \frac{1}{\delta(x)} \cdot \frac{\partial \delta(x)}{\partial x} \quad (1)$$

The photovoltaic cell under intense illumination are operating at high temperatures, we assume that the operating temperature is about 325 K. This led us to use electronics, diffusion and mobility parameters at this temperature. We neglected the contribution of the emitter. In our model the photocurrent density is given by the following equation:

$$J_n(x, E_0) = e \cdot D_n \cdot \frac{\partial \delta(x, E_0)}{\partial x} - e \cdot \mu_n \cdot E(x) \cdot \delta(x, E_0) + e \cdot \mu_n \cdot E_0 \cdot \delta(x, E_0) \quad (2)$$

From the above assumptions, we have established the continuity equation of minority charged carriers generated in the base, which is given by:

$$\frac{\partial^2\delta(x,E_0)}{\partial x^2}+\frac{L_{E_0}}{{L_{np}}^2}\cdot\frac{\partial\delta(x,E_0)}{\partial x}-\frac{\delta(x,E_0)}{{L_{np}}^2}=-\frac{C}{D_{np}}\cdot\sum_{i=1}^{3}a_i\cdot e^{-b_i\cdot x} \quad (3)$$

With $D_{np}=\dfrac{2\cdot\mu_n\cdot D_n+\mu_p\cdot D_n-\mu_n\cdot D_p}{\mu_n+\mu_p}$ (4)

$${L_{np}}^2=D_{np}\cdot\tau \quad (5)$$

$$L_{E_0}=\mu_n\cdot E_0\cdot\tau \quad (6)$$

From the tabulated values of the solar spectrum [11], the coefficients a_i and b_i are given for AM 1.5 as follow:

Table 1. Values of the solar spectrum

$a_1=6.13\cdot10^{20}$	$a_2=0.54\cdot10^{20}$	$a_3=0.0991\cdot10^{20}$
$b_1=6630$	$b_2=1000$	$b_3=130$

The resolution of the equation (3) lead to the expression of the charged carriers density generated in the base *δ(x, E₀)*.

3. RESULTS AND DISCUSSION

For the numerical processing of the equations, we used the following values: *$S_b=10^3$cm/s; $\mu_n=1{,}19.10^3$cm²/V.s; $\mu_p=376{,}941$cm/s; D_n = 35,933 cm²/s; D_p = 11,379 cm²/s; H = 0,03cm; C = 50 suns; T = 325K cm²/s; S_{f0}=10cm/s; S_f = 4.10^4 cm /s*

3.1 Short Circuit Photocurrent Density

The expression of the photocurrent density as a function of the intensity of the electric field is given by the equation (7) below [7]:

$$J_{ph}(E_0)=eD_{np}\left.\frac{\partial\delta(x,E_0)}{\partial x}\right|_{x=0}+e\mu_nE_0\delta(0,E_0) \quad (7)$$

At the vicinity of the short circuit, the junction dynamic velocity S_F tend to infinite and we obtain the expression of the short circuit photocurrent J_{cc} given by the equation (8) below :

$$J_{cc}(E_0)=eD_{np}\sum_{i=1}^{3}k_i\frac{\beta(D_{np}b_i-S_B)(e^{-H(\alpha+b_i)}-\cosh(\beta H))+\left[\beta^2D_{np}-(\alpha D_{np}+S_B)(\alpha+b_i)\right]\sinh(\beta H)}{(\alpha D_{np}+S_B)\sinh(\beta H)+\beta D_{np}\cosh(\beta H)} \quad (8)$$

With: $\alpha=-\dfrac{L_{E_0}}{2\cdot{L_{np}}^2}$, $\beta=\dfrac{1}{2\cdot L_{np}}\cdot\sqrt{(\dfrac{L_{E_0}}{L_{np}})^2+4}$ and

$$k_i=\frac{C\cdot a_i\cdot{L_{np}}^2}{D_{np}\cdot(1+L_{E_0}\cdot b_i-(b_i\cdot L_{np})^2)} \quad (9)$$

The Fig. 2 show the variations of the short circuit photocurrent as function of the electric field intensity:

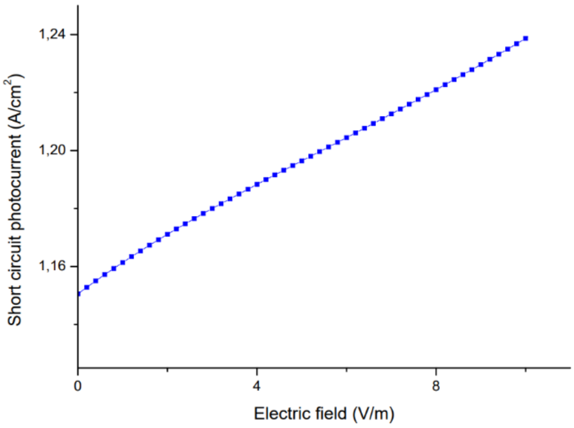

Fig. 2. Short circuit photocurrent density versus electrical field intensity

3.2 Open Circuit Photovoltage

The photovoltage through the photovoltaic cell is given by equation (10) below [12,13]:

$$V_{ph}(E_0) = V_T \ln\left[\frac{\delta(0,E_0)}{n_0} + 1\right] \tag{10}$$

With $V_T = \frac{K_B T}{e}$ and $n_0 = \frac{{n_i}^2}{N_B}$ (11)

V_T represent the thermal photovoltage, n_0 represent electrons density at thermodynamic equilibrium, N_B is the doping rate of the base ($N_B = 10^{16}\ cm^{-3}$) and n_i, the intrinsic concentration ($n_i = 10^{10}\ cm^{-3}$). At the vicinity of open circuit, $S_F \rightarrow S_{F0}$ and we obtain the expression of the open circuit photovoltage given by the following equation (12):

$$V_{co}(E_0) = V_T \ln\left[\frac{D_{np} N_B \sum_{i=1}^{3} k_i(\beta(D_{np} b_i - S_B)(e^{-H(\alpha+b_i)} - \cosh(\beta H)) + \left[\beta^2 D_{np} - (\alpha D_{np} + S_B)(\alpha + b_i)\right]\sinh(\beta H))}{ni^2(\left[\beta^2 {D_{np}}^2 + (\alpha D_{np} + S_B)(S_{F0} - \alpha D_{np})\right]\sinh(\beta H) + \beta D_{np}(S_B + S_{F0})\cosh(\beta H))} + 1\right] \tag{12}$$

The Fig. 3 below presents the variations of the photovoltage as a function of the electric field intensity:

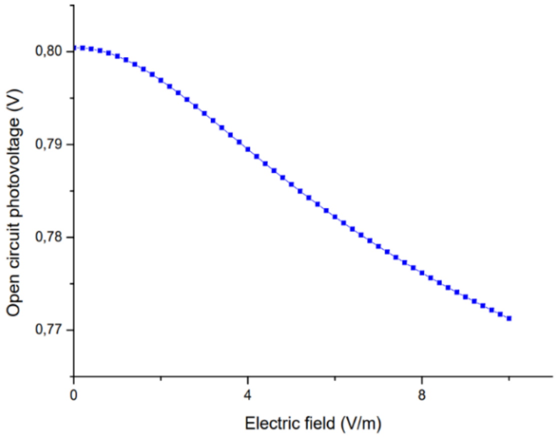

Fig. 3. Open circuit voltage versus electrical field intensity

We observe on the Fig. 3 that the open circuit photovoltage decrease with the increase in the electric field intensity. This can be interpreted by the fact that, in the open circuit situation the junction is block. The illumination mode and the electric force lead to increase of collisions between the charged carriers in the base of the photovoltaic cell. Thus, possibilities for recombination of charged carriers increase and lead to decrease in open circuit photovoltage. We notice that the rate of decrease in the open circuit photovoltage is relatively slow.

3.3 Electric Power Delivered

The electric power delivered by the photovoltaic cell is given by equation (13) below [12,14]:

$$P_{él}(E_0) = J_{ph}(E_0) \cdot V_{ph}(E_0) \tag{13}$$

The influence of the electric field on the electric power is illustrate on the Fig. 4 below:

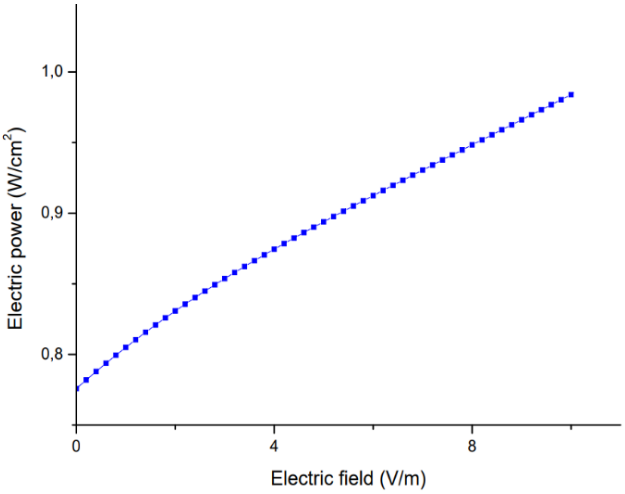

Fig. 4. Electrical power versus electrical field intensity

We observe on the Fig. 4 that the electric power delivered by the photovoltaic solar cell increase with the increase in electric field intensity. In fact, the electric power is the product of photocurrent by photovoltage. But, it comes out from previous results that photocurrent and photovoltage increase with the increase in electric field intensity, this lead to an increase in the electric power delivered by the photovoltaic cell. Increase of the electric power with increase in the electric field intensity is in good agreement with previous results.

3.4 Series Resistance

Series resistance is obtained by applying mesh law in the equivalent electric circuit of a photovoltaic cell at the vicinity of the open circuit. It expression is given by the equation (14) below [12]:

$$R_s(E_0) = \frac{V_{co}(E_0) - V_{ph}(E_0)}{J_{ph}(E_0)} \tag{14}$$

Evolution of the series resistance as function of the electric field is illustrate on the following Fig. 5:

The analysis of the Fig. 5 shows that increase in the electric field intensity lead to the increase in the series resistance. We explain this result by the fact that, the electric field throughout the electric force make it easy for the charged carriers generated in the base to reach the junction. This lead to the decrease in the series resistance. This result is in good agreement with the increase in the short circuit photocurrent.

3.5 Fill Factor

The fill factor is given by the equation (15) below [3,12]:

$$FF(E_0) = \frac{P_{él\max}(E_0)}{J_{cc}(E_0).V_{co}(E_0)} \tag{15}$$

The Fig. 6 below present the curve of fill factor versus electric field intensity:

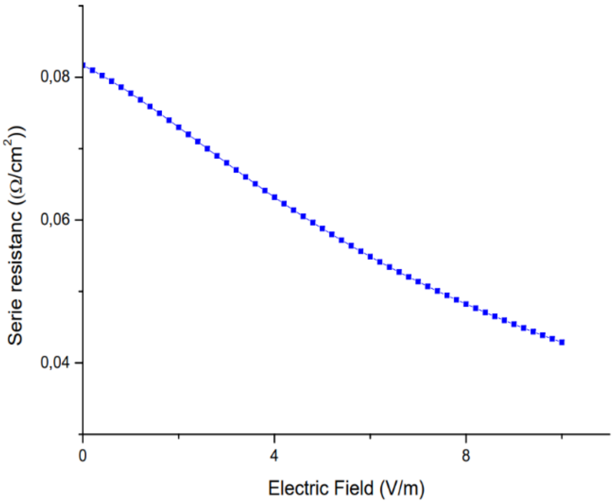

Fig. 5. Series resistance versus electric field intensity

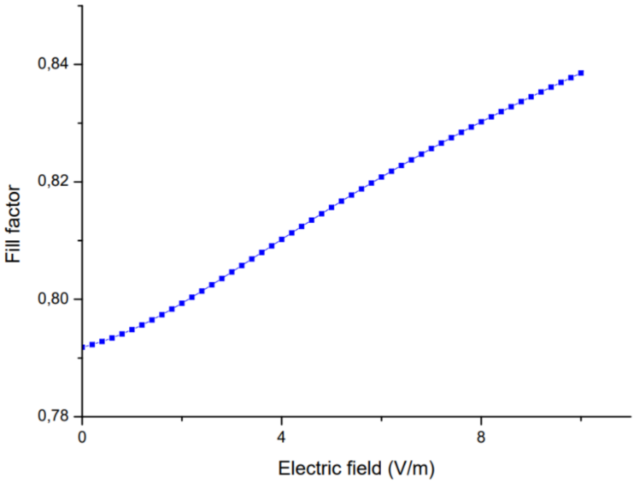

Fig. 6. Fill factor versus electrical field intensity

The analysis of the curve of the Fig. 6 shows that fill factor increases with the increase in electric field intensity. This result is in good agreement with the previous results.

3.6 Conversion Efficiency

The conversion efficiency of a PV solar cell is given by the equation (16) below [3,12]:

$$\eta(E_0) = \frac{P_{él\max}(E_0)}{P_{inc}} \tag{16}$$

The photovoltaic solar cell being under intense illumination, the incident power P_{inc} is determinate from the following expression [15]:

$P_{inc} = 0,072\ \ W / cm^2 \times C$; *C* represent the number of suns and *C* = 50 suns and $P_{inc} = 3,6\ \ W / cm^2$ in the Air Mass 1.5.

We present on the Fig. 7 the curve of the conversion efficiency of the PV cell versus the electric field intensity:

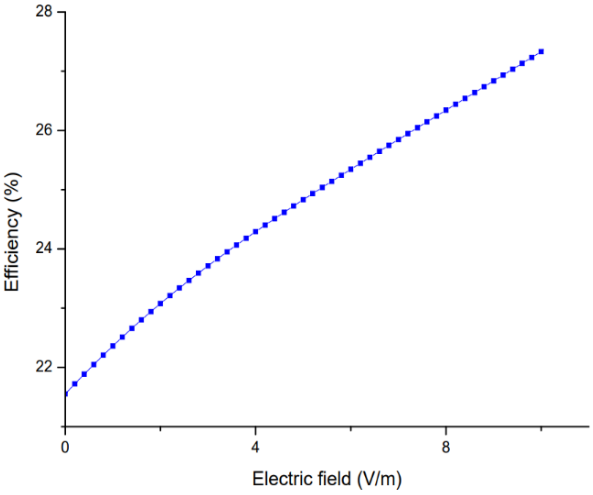

Fig. 7. Efficiency profile versus electrical field intensity

It appears on the Fig. 7 that increase in the electric field intensity lead to the increase in conversion efficiency. This result is in good agreement with those of electric power and fill factor [16-19].

4. CONCLUSION

This work allow us to understand the behaviour of the electric parameters of a photovoltaic solar cell under intense illumination and an external electric field. It appears in this study that the presence of a electric field pointing in a certain direction improve the performances parameters of a photovoltaic cell under intense illumination except the open circuit photovoltage which decrease. Because of intense illumination and the high photogeneration of charged carriers, the photovoltaic cells under intense illumination operate under very high temperature. For the future works, we wish to take into account the effect of the heating of the base, because intense illumination lead to heating of the base.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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