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TOWARDS A STUDY OF THE CONCENTRATION EFFECT IN CPV TECHNOLOGIES. CASE OF NOOR OUARZAZATE

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***Abstract*— In a difficult energy and economic context, the expectations in terms of renewable energies in general and solar energy in particular, are more and more important The major challenges for researchers and industrialists in this field are to increase the efficiency and reduce the costs of cells, modules and photovoltaic systems in order to make them as competitive as possible. In this context, we are focused in this paper on two technologies: photovoltaic (PV) technology and concentrated photovoltaic (CPV). First, we will present generalities and notions on the CPV technology, solar energy and solar radiation. World markets will be cited, but also the Moroccan market with a special mention of Noor Ouarzazate station in southern Morocco. The second part is dedicated to two modelling and simulation of a CPV cell performed under Matlab / Simulink software; these simulations are done under different sunshine conditions, and different concentrations. A comparison between the performances and yields of the two CPV modelling and the PV technology, will be exposed. All for practical validation with real data from the Noor station.**

***Keywords*— PV, CPV, Modeling, Trackers, Irradiation, Matlab**

I. INTRODUCTION

In a difficult energy situation, marked by the foreseeable exhaustion of fossil fuels and their impact on the environment, expectations in terms of renewable energy in general and solar energy in particular, are increasingly important. These energies and in particular solar energy are considered the energy solution of the future. Solar energy is one of the "free" renewable energies, capable of reducing pollution ensuring acceptable performance. The major challenge for researchers and industry in this area is to further improve the efficiency of photovoltaic systems to maximize production facilities and solar power plants. Another major challenge for current research in the field of photovoltaic is lower facilities and power costs through cost reduction systems and photovoltaic devices such as solar cells, modules and photovoltaic panels as well as the mechanical structure to support and position. The cost of photovoltaic cells, which is the most important component of a photovoltaic system as part of energy conversion, remains quite expensive and this is one of the major drawbacks of this energy. Modules or photovoltaic panels and the mechanical structure to support and position is also a big issue in this technology.

The work presented in this paper concerns a modeling of a concentrated photovoltaic cell (CPV). In the first part, we will present generalities on CPV technology, solar energy and solar radiation, and then we describe the main notions of the CPV. World markets will be cited, but also the Moroccan market with a special mention of Noor Ouarzazate station in southern Morocco.

The second part is dedicated to the modelling and simulation of a CPV cell performed under Matlab / Simulink software; these simulations are done under different sunshine conditions, and different concentrations.

In the last part of the paper, a discussion of the simulation results will be presented. All for practical validation with real data from the Noor station.

II. CONCENTRATED PHOTOVOLTAIC (CPV)

A. CPV Technology

Concentrated photovoltaic (CPV) has been widely recognized as the technology that holds the highest hopes for meeting the energy challenges facing the world.

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A concentrated photovoltaic system converts light energy into electrical energy in the same way as the conventional photovoltaic technology. The difference with the CPV has the addition of an optical system that concentrates a large area of sunlight onto each cell of the panels, as shown in figure 1. Science is interested in photovoltaic concentrated since the 1970s, but it is only now that the CPV reached commercial viability. This is the latest technology that goes into the solar sector.

CPV systems can be compared with telescopes that follow the sun's position and bring the concentrated light to the cell.

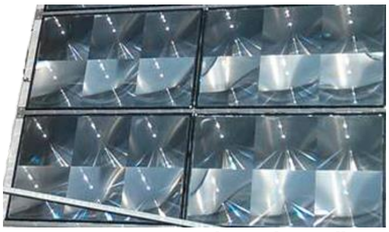

Fig. 1. Concentrating photovoltaic cell

B. CPV operating principle

The mirrors focus sunlight onto a small photovoltaic solar cell high efficiency. With this concentration technology, semiconductor materials can be replaced by less expensive optical systems. At equal power, this allows the use of 1000 times less PV material than in the photovoltaic panels to direct sunlight. CPV modules require direct sunlight; it should not be any obstacles like clouds for example, between the sun and modules. This also means that the system must continuously monitor the sun in order to receive direct radiation (or DNI: Direct Normal Irradiation), thanks to a monitoring structure known as "Tracker" because it only works when the sun is visible.

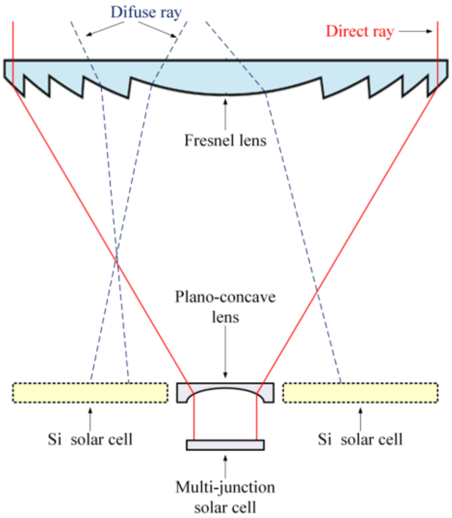

Fig. 2. Fresnel-type CPV System [1]

III. CONCENTRATED PHOTOVOLTAIC TECHNOLOGY (CPV)

C. Parabolic Mirrors

The parabolic mirror reflects the sunlight onto a photovoltaic cell to generate electricity. This technology is also widely used in concentration.

Fig. 3. Parabolic mirrors

The Fresnel mirror is based on the same technology as Fresnel lenses. The mirrors allow flattening a parable in the "cutting" in several sections. The occupied space is small compared to a classic dish and wind resistance is lessened because each mirror movement is controlled by motors. One can thus orient the mirrors to control the concentration (for example to add or remove the focusing of a mirror), or switch to safety position by positioning the flat (in case of strong wind).

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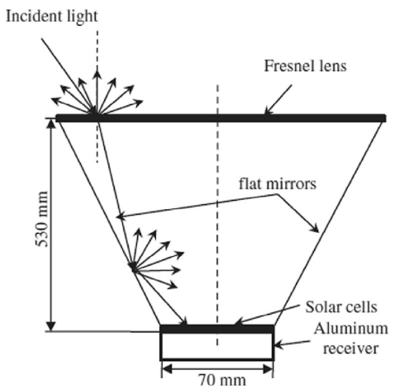

Fig. 4. Fresnel mirror in CPV system [2]

D. Mirrors

Some solar power plants Concentrating (CPV) use for its Fresnel lenses to focus the light rays onto solar cells high efficiency. For the same captured solar flux, energy yields achieved today (30% to 40% for lens and sensor) are double those of the photovoltaic solar panels to direct sunlight (around 10% and up to 20%).

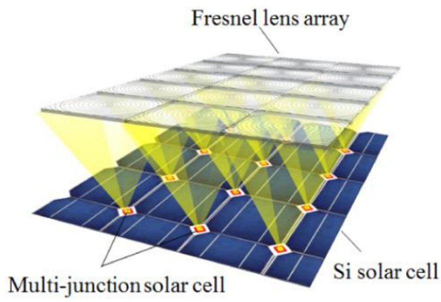

Fig. 5. CPV based on Fresnel lens [3].

IV. E.WOLRD AND MOROCCAN CPV MARKETS

E. World market

CPV technology is subject, like all technologies whose performance affects the economic development, uncertainties and other vicissitudes affecting the world energy market.

In fact, thanks to all these points of strength, CPV technology is booming since 2010 and this has been realized on the market by the appearance of several stakeholders such as module manufacturers and developers of CPV plants tracker. This growth has also led to the installation of large CPV plants of ten megawatt, as shown in figures 6 and 7.

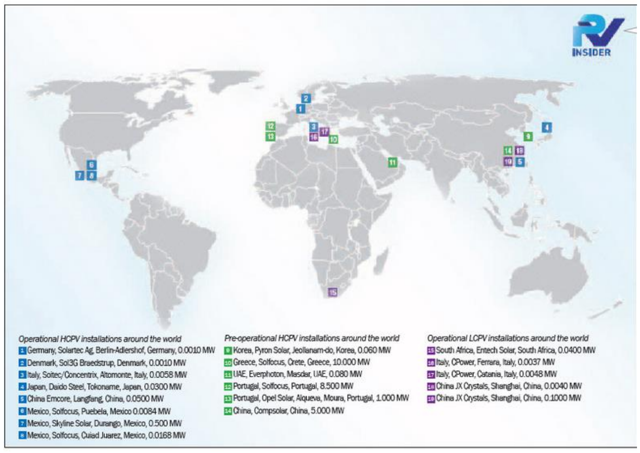

Fig. 6. Largest operating CPV power plants worldwide. [4][16]

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
MW	46	108	160	240	425	622	804	982	1 172	1 362

Fig 7. Overall forecast of installing the CPV system (megawatts) [5].

F. In Morocco

Located in the north-western part of the African Continent, Morocco faces the Sahara Desert in the south and its solar radiation is very high. This means that the country has a great potential for solar energy generation, it stated.

In Morocco, in order to increase its electricity self-sufficiency by making an effective use of its rich solar energy resource, the government intends to introduce 2,000 MW and 4,500 MW solar energy power generation facilities by 2020 and 2030 respectively.

Morocco has a huge solar potential. The country intends to massively exploit this clean and inexhaustible energy in the next decade. The stated objective of the Kingdom is to decrease the external energy dependence from 95% to 85% in 2020. The state has thus set a goal of producing 14% of its electricity needs through solar energy [12].

Morocco has just launched the construction of the fourth extension of the Noor solar power plant, called Noor-IV, one of the largest in the world based on PV and CPV technology. This facility is expected to eventually provide electricity to more

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than two million people. This new project, whose operation has just begun, is developed over an area of 137 hectares and will have a production capacity of 72MW. Its construction represents an investment of 750 million dirhams (70 million euros), mainly financed by the German bank KfW, which contributes 659 million dirhams (61 million euros). The Noor-IV project is operated by a consortium comprising: the Moroccan Agency for Sustainable Energy: ¨Masen¨, and the Saudi company ¨Acwa Power¨, already authorized to operate other tranches of the project. Its operation is scheduled for the first quarter of 2018.

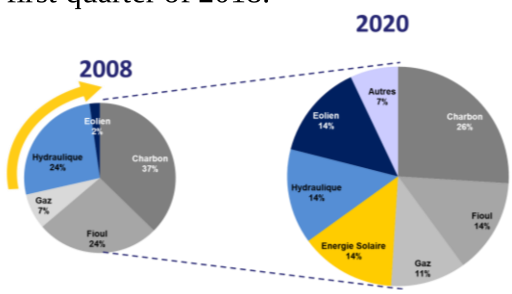

Fig. 8. Morocco's energy prospective for 2020

The year 2018 is a historic year for Noor Ouarzazate. In the first quarter of this year, all plants of this solar complex (Noor Ouarzazate I, II, III and IV) are in service. And with a capacity of 582 megawatts (MW), these plants will officially Noor Ouarzazate largest multi-technology solar production site in the world. Solar power plants Noor Ouarzazate II, III and IV are in the final stages of construction. They will be ready before the end of March 2018 [6]. Figure 9 shows the 1MW CPV plant in Ouarzazate at the Noor station.


Fig. 9. CPV plant in Noor IV Ouarzazate

V. Modelling and simulation of CPV cell

G. *Modelling of CPV cell*

The basic model of a CPV generator is based on the same model of a PV generator except that introduces an optical concentrator (mirror or lens). Figure 10 shows a PV cell.

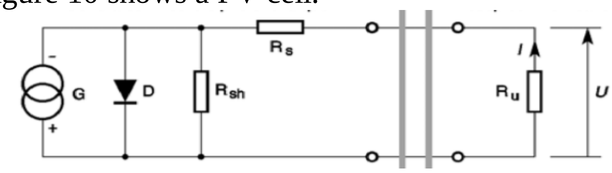

Fig.10. Equivalent circuit diagram of a PV generator [7]

I_{PH} is an ideal current source, D is a diode materializing the fact that the current flows in only one direction. RSH is the shunt resistor that takes into account the inevitable current leaks that occur between the opposite positive and negative terminals of a photocell (micro short circuit in silicon in particular). RS is the series resistance, which is due to the different electrical resistances that the current encounters on its path (intrinsic resistance of the layers, resistance of the contacts). Finally, the load is the impedance of the receiver which imposes the operating point on the photocell as a function of its current-voltage characteristic at the considered irradiation (in the case where the receiver is comparable to a resistor).

n: Ideality factor (practically $1 \leq n \leq 5$). T: Temperature of the junction (in ° K). $I_{PH}=Icc.(E_s/1000)$ Es is the given Irradiation

The CPV cell basic equation is therefore:

$$I = I*_{oc}.\left(\frac{E_S}{1000}\right) - Io.\left(\exp\left(q.\left(\frac{V*_{oc}+R_S.I}{n.K.T}\right)-1\right) - \left(\frac{V*_{oc}+R_S.I}{R_{sh}}\right)\right. \quad (1)$$

With: $$I = I_{ph} - I_d - I_{sh}$$

$$I_{ph} = I*_{oc}.\left(\frac{E_s}{1000}\right)$$

$$I_d = Io.\left(\exp\left(q.\left(\frac{V*_{OC}+R_S.I}{n.K.T}\right)-1\right)\right.$$

$R_s = 0\,\Omega$ (In the ideal case)

$$I_{sh} = \left(\frac{V*_{OC}+R_S.I}{R_{sh}}\right)$$

In the ideal case $R_{sh} = 1M\Omega$

$$V*_{oc} = V_{oc} + \frac{K.T}{q.Ln\,C_{opt}}$$

$$I*_{oc} = C_{opt}.I_{sc}$$

With:

I_o = Is: The saturation current of the diode in amperes (A)
I_{Ph}: The photovoltaic current.
q: Charge of an electron ($1.6 * 10^{-19}$ C).
K: Boltzmann Constant ($1.38 * 10_{-23}$ J / K).
n: ideality factor (n=1,5).
T: Temperature of the junction (in k).
V^*_{oc} Open circuit voltage of CPV cell.
V_{oc}: open circuit voltage of PV cell.
I^*_{oc}: The short circuit current of CPV cell.

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I_{sc}: The short-circuit current of PV cell ($I_{sc} = 7.34\ A$).

C_{opt}: The optical concentration ratio

H. Matlab model of CPV cell

The Matlab model of a CPV cell is shown in figure 11.

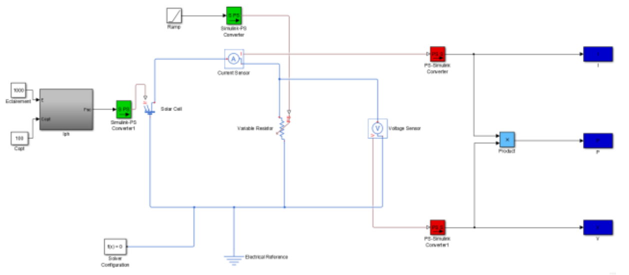

Fig. 11. Model of a CPV cell with PV circuit cell

I. Simulation results for CPV cell

Exposed respectively to an irradiation of E=1000W/m² and E=W/m² and for an optical concentration ratio of Copt=100 then Copt=10, the characteristics I =f (V) of the Matlab CPV cell are shown in figure 11.

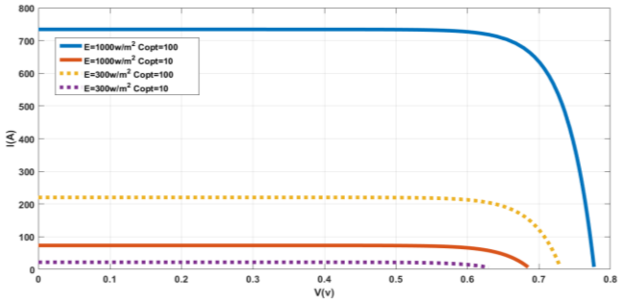

Fig.12. Characteristics I=f(V) of a CPV cell for different irradiations and optical concentration ratios

The characteristics P=f(V) of the Matlab CPV cell under an irradiation of E=1000W/m² and E=300W/m², and an optical concentration ratio of C_{opt}=100 then 10, are shown in figure 13.

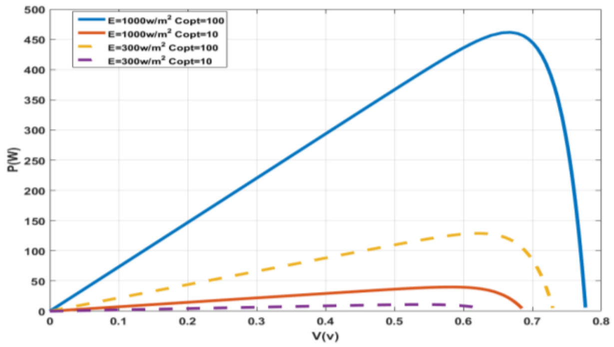

Fig. 13. Characteristics P = f (V) of a CPV cell under different irradiations and optical concentration ratios.

J. Modelling of CPV cell circuit

The equation used to simulate the cell CPV circuit is:

$$I = C_{opt}.I_{sc}.\left(\frac{E_s}{1000}\right) - Io.\left(\exp\left(q.\left(\frac{V_{OC}+R_S.I}{n.K.T}\right)-1\right) - \left(\frac{V_{OC}+R_S.I}{R_{sh}}\right)\right) \quad (2)$$

The cell simulation diagram CPV circuit is shown in figure 14.

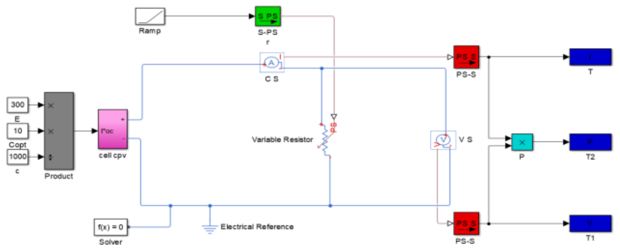

Fig.14. Matlab model of the CPV cell with PV circuit cell.

K. Simulation results for CPV cell circuit

Subjected to respectively an irradiation of E=1000W/m², and E=300W/m², and a ratio of optical concentration of Copt =100 then Copt=10, the characteristic I= f (V) of the cell CPV circuit is shown in figure 15.

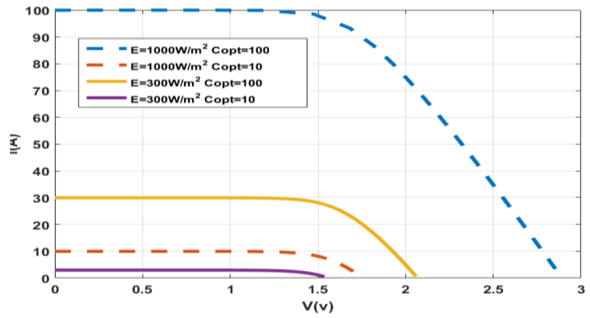

Fig.15. Characteristics I= f(V) of a CPV circuit for different irradiations and optical concentration ratios

The characteristic P = f (V) of the cell CPV circuit under illumination of E=W/m², and E=W/m², and to an optical concentration ratio of Copt= 100 then 10 is shown in figure 16.

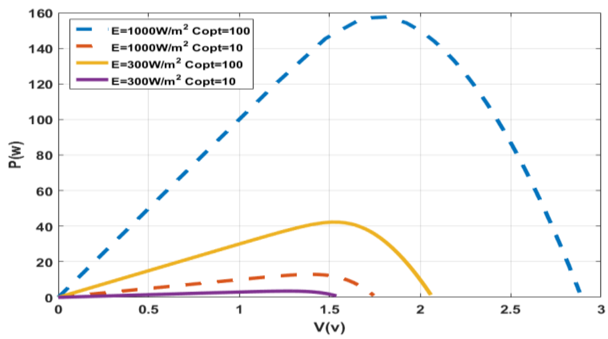

Fig. 16. Characteristics P= f (V) of the cell circuitry CPV circuit under different illumination and optical concentration ratios.

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From the simulations above we can conclude that:

- For the voltage: There has been a slight increase in voltage 1.55V between PV [15] and CPV technology.
- For the current: Comparing the simulation results of both PV and CPV cells, there is a current increase of 7.3 A for the PV cell, 90 A as a maximum current value of the CPV cell, with an optical concentration ratio of Copt=10.
- For the electrical power under Copt = 100, there is a large increase in power of 35 W, as the maximum power of the PV cell to the value of 470 W for the CPV cell.

All these comparisons lead us to conclude that the concentration PV cell has a very high energy efficiency compared to a PV cell under the same irradiation. The performance of PV and CPV cell is strongly influenced by climatic conditions, particularly the lighting and the radiation concentration.

VI. CONCLUSIONS

In this paper, we contributed to the comparative study and modelling of CPV technology for power generation,

According to the results, it is good to note that the CPV cells have an important performance versus PV cells, for this reason that we can sum up this performance increase in the concentration effect.

The use of this technology as an emerging renewable energy is highly increasing, thanks to its efficiency, its importance for the preservation of the environment. It is also because it does not emit greenhouse gases, produces no waste and does not involve any significant risk and no significant nuisance.

The energy efficiency is raised when we use the CPV technology compared to the PV one, and under the same environmental conditions. The next step for this work is to implement real data from the Noor CPV station in Ouarzazate, to validate the modelling performed in this study.

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