Chapter

Concentrator Photovoltaic System (CPV): Maximum Power Point Techniques (MPPT) Design and Performance

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Abstract

The research carried out in this work aimed to study the performance of MPPT techniques applied to the Concentrator Photovoltaic (CPV) System for the research and the pursuit of the Maximum Power Point (MPP).This study presents a modeling and simulation of the CPV system. It consists of a PV module located in the focal area of a parabolic concentrator, a DC / DC converter (Boost), two MPPT controls (P&O and FL) and a resistive load. This chapter presents the two MPPT techniques (P&O and FL) performances. The obtained results show the importance of cooling systems integration with CPV system. This hybrid system design results in good MPPT P&O and FL performance. The numerical results obtained with Matlab/Simulink® software have generally shown that the two MPPT controls result in better performance in terms of speed, and accuracy, stability. In fact they showed that the CPV system is stable.

Keywords: Concentrator photovoltaic System (CPV), Converter DC-DC (Boost), MPPT Techniques, Performances, Perturb & Observe (P&O) algorithm, Fuzzy Logic (FL) algorithm, Matlab/Simulink®

1. Introduction

Today, Concentrator Photovoltaic (CPV) systems are among the important technologies for converting solar radiation into electrical energy. Despite the high cost of this technique, the CPV system attracted attention last years many researcher for their high power output compared with conventional module systems. Santosh Kumar Sharma et al. [1] designed the aspects and the performance of a rooftop grid-connected solar photovoltaic power plant (RTGCSPVPP). The RTGCSPVPP is installed at Gauri Maternity Home Ramkrishna Puram Kota Rajasthan, India for supplying the energy to whole hospital building. T. Mrabti, et al. [2] presented the implementation and operation of the first installation prototype high concentration photovoltaic (CPV) in Morocco. This installation is formed by three two-axis sun trackers connected to the national electricity grid. In fact, they showed the first experimental results concerning the electrical operation of this plant and its daily energy production as a function of meteorological conditions.

On the other hand, photovoltaic modules are expensive and their electrical characteristics suffer from climatic variations, it is therefore necessary to extract the maximum power to increase the efficiency of the module [3]. A.Saxena et al. [4] evaluated the non-linear I-V characteristics of a photovoltaic solar module and its maximum power point which depends on climatic conditions (temperature and irradiation).

Additional, the PV module efficiency is limited for two reasons: first, part of the solar radiation is converted into heat. Second, the module temperature increases during the energy production. Therefore, the use of a cooling system becomes necessary. Sanjeev et al. [5] presented the various cooling technologies available for CPV systems and they showed that cooling systems can provide an uniform and low cell temperature.

Also, there are many techniques called MPPT (Maximum Power Point Tracking) [6]. The most common MPPT methods are Perturb & Observe (P&O) and the Incrementation of Conductance (INC). Other MPPT algorithms include the use of a Fuzzy Logic Controller (FLC), an Artificial Neural Network (ANN), [7–9].

D. Djalel, et al. [10] showed the MPPT techniques (P&O and Fuzzy logic) performance under STC or Standard Test Conditions, which correspond to irradiation G of 1 kW/m^2 at spectral distribution of AM1.5 and a cell temperature T of 25°C. Then they carried out a comparison between these two MPPT controls. According to the simulation results, the fuzzy logic method generates good performance: low oscillating, more stable operating point than P&O and important precision to operate the MPP. M. A. Enany et al. [10] have modeled and simulated same MPPT techniques such as: ANFIS, FCO, Fuzzy logic, Increment of conductance, Disturbance and P&O observation. Then they compared between these techniques. And they concluded that the ANFIS method and fuzzy logic control present the best performance.

The previous studies mentioned below do not take into consideration the photovoltaic concentration conditions. To our knowledge, the MPPT techniques performance in these conditions has rarely been studied in the open literature. In order to further the study of CPV systems, improvements have been made to the present study, including the integration of the cooling system with adequate temperature and the evaluation of the performance behavior of the commercial PV module.

The purpose of this chapter is to compare the performances of two MPPT techniques P&O and FL for a CPV system in the aim to determine the suitable technique.

This chapter is organized as follows. Part 2 describes the modeling a PV module placed at the focus of a parabolic concentrator. Part 3 presents the improvement of a proposed CPV module with a cooling system, then the simulation of this global system consisting of a CPV module, a boost converter, two MPPT algorithms (P&O and FL) and a resistive DC / DC load. Part 4 presents numerical results and a comparison between the two MPPT techniques. Finally, Part 4 concludes this work.

2. Modeling a PV module placed at the focus of a parabolic concentrator

In order to achieve a higher efficiency of a PV module, we propose to place it in the focal space of a concentrator composed by a double reflective parabolic concentrator, **Figure 1**.

This system is composed by:

- ***A first reflector:*** is a heliostat as a sun tracking system with a reflection coefficient equal to 1.

- ***A second reflector:*** is a parable that is composed of a set of curved mirrors. Its role is to reflect and focus the light received by the heliostat on a receiver placed in the focal space of the parabolic concentrator.

- ***A receiver:*** is a fixed photovoltaic module that concentrates the received radiation.

Figure 1 shows the block diagram of the proposed photovoltaic system. This system is composed by the following elements:

- A PV module placed in the focal space of a concentrator
- A DC/DC converter Boost type
- Resistive load
- And an MPPT controller

In the state of solar concentration, the output current module, denoted I_{PV}, is given by (Eq. (1)), [11]:

$$I_{PV} = N_p I_{ph} - N_p I_s \left[\exp\left(\frac{\frac{V_{PV}}{N_s} + \frac{IR_s}{N_p}}{nV_{th}} \right) - 1 \right] - \frac{\left(\frac{N_p V_{PV}}{N_s} + IR_s \right)}{R_{sh}} \quad (1)$$

The photo current I_{ph} is mainly depending on the incident irradiance and the cell operating temperature. It can determine using (Eqs. (2) and (3)), [12]:

$$I_{ph} = \frac{G}{G_{ref}} \left(I_{sc,ref} + K_i.\Delta T \right) \quad (2)$$

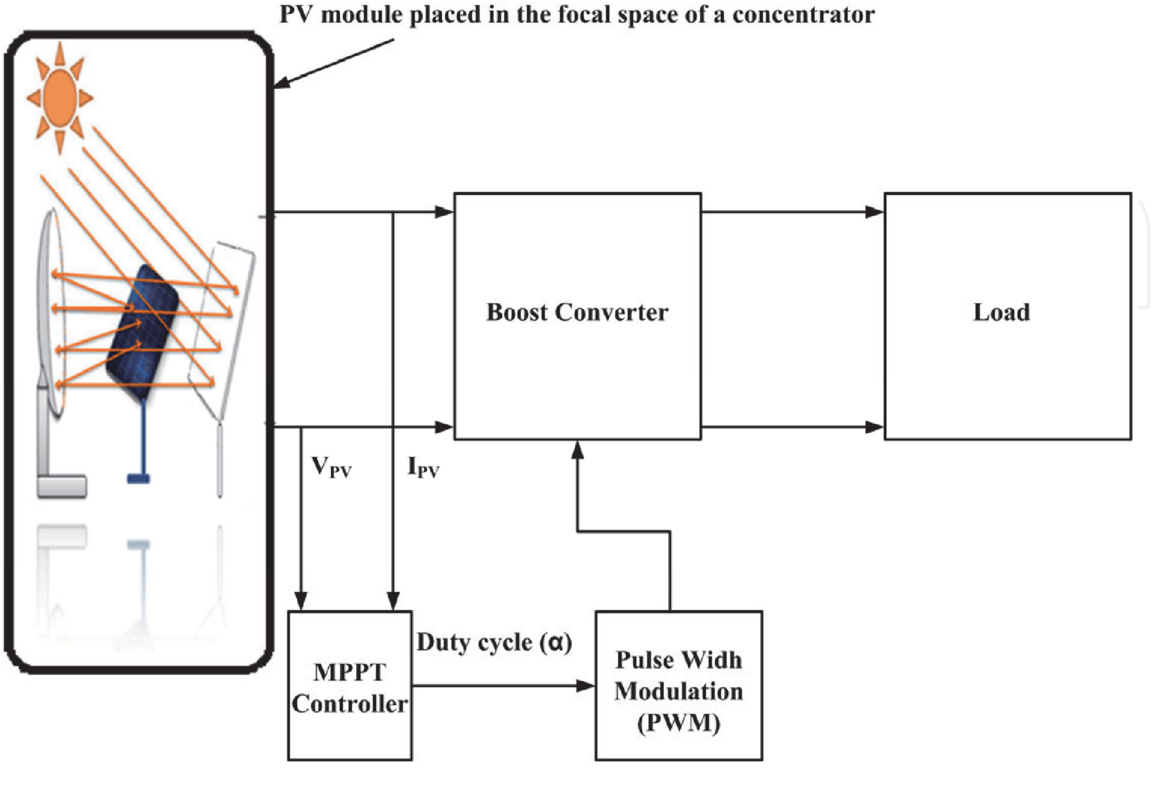

Figure 1.
Proposed CPV system.

where

$$\Delta T = T - T_{ref} \tag{3}$$

The cell operating temperature T varies with the incident irradiance, which is described by (Eq. (4)), [13]:

$$T = T_{amb} + \left(\frac{T_{NOCT} - 20}{800}\right)G \tag{4}$$

The diode saturation current I_s at any operating conditions is related to its reference conditions by the following equation, [7]:

$$I_s = I_{s,ref}\left(\frac{T}{T_{ref}}\right)^3 \exp\left[\frac{qE_g}{nK}\left(\frac{1}{T_{ref}} - \frac{1}{T}\right)\right] \tag{5}$$

The reverse saturation current at STC condition $I_{s,ref}$ is depending on open circuit voltage (V_{oc}) and can be calculated by (Eq. (6)), [12]:

$$I_{s,ref} = \frac{I_{sc}}{\exp\left(\frac{V_{oc}}{nV_{th}}\right) - 1} \tag{6}$$

The material band gap energy E_g is obtained by (Eq. (7)) using Varshni relation, [6, 14].

$$E_g(T) = E_g(0) + \frac{\alpha T^2}{T + \beta} \tag{7}$$

Table 1 E_{g0}, α and β silicon parameters [13]:

	E_{g0} (T = 0 K)	$\alpha.10^{-4}$, eV/K ^{2}	β, K
Si	1.17	4.73	636

Table 1.
The E_{go}, α and β silicon parameters

Then, the Si band gap as a function operating temperature is determined by (Eq. (8))

$$E_g(T) = 1.17 + \left(\frac{4.73 \cdot 10^{-4} T^2}{T + 636}\right) \tag{8}$$

The series resistor module R_s can be approximately expressed by (Eq. (9)), [15]:

$$R_s = R_{s,ref} - \left[\frac{n}{I_s}\exp\left(\frac{-V_{oc}}{n}\right)\right] \tag{9}$$

$R_{s,ref}$ is the module series resistor measured at STC (Ω)

The shunt resistor module R_{sh} is inversely proportional to irradiance incident on the CPV module and is given by (Eq. (10)), [15]:

$$R_{sh} = R_{sh,ref}\left(\frac{G_{ref}}{G}\right) = R_{sh,ref}\left(\frac{1}{C}\right) \tag{10}$$

where the concentration ratio C is defined by (Eq. (11)):

$$C = \frac{G}{G_{ref}} \tag{11}$$

$R_{s,ref}$ is the module shunt resistor measured at STC (Ω)

The diode ideality factor n is considered according to $C = \frac{G}{G_{ref}}$ as function of cell operating temperature and reference cell temperature, [15]:

$$n = n_{ref} \frac{T}{T_{ref}} \tag{12}$$

For Si-poly, n_{ref} = 1.3 is the diode ideality factor at STC, [13]

The thermal voltage of the cell V_{th} is defined by (Eq. (13)):

$$V_{th} = \frac{KT}{q} \tag{13}$$

K is the Boltzmann constant, 1.38×10^{-23}J/K, q is the Electron charge, 1.602×10^{-19}C.

3. CPV system configuration improvement

To improve the CPV system performance, the PV module temperature must be reduced. Hence the interest of inserting a heat sinks. Thus we will assemble the concentrator with a cooling system below the PV module to maintain the value of its temperature constant.

An active dissipation exchanger will be used to maintain the module temperature at 35°C. **Figure 2** represents the modification made to the PV module, [16, 17].

SOLKAR make 36- Watt, Photovoltaic module is taken as the reference module for simulation and the manufacturer specifications details are given in **Table 2**.

The module series resistor and the module shunt resistor of SOLKAR Photovoltaic Module are supposed ideal by, [2] and are fixed successively at $R_{s,ref} = 0.001\Omega$ and $R_{sh,ref} = \infty$.

Based on (Eq. (1)), the solar module model was implemented in MATLAB/ Simulink® environment.

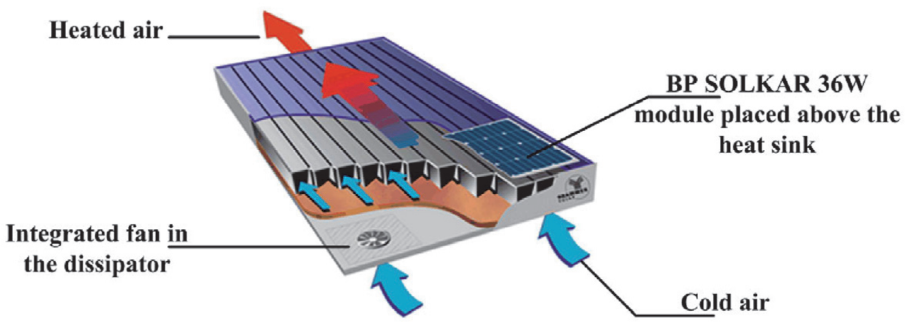

Figure 2.
Heat sink placed below the PV module under the solar concentration condition.

Maximum Power P_m	$37.08W$
Voltage at Maximum power V_m	$16.56V$
Current at Maximum power I_m	$2.25A$
Open circuit voltage V_{oc}	$21.24V$
Short circuit current I_{sc}	$2.55A$
Number of series Cells N_s	36

Table 2.
SOLKAR datasheet values at STC.

4. Boost converter model

Figure 3 shows the boost converter structure used in this chapter. The boost converter is composed with a MOSFET and Diode switching elements where are supposed to be ideal, a resistor, inductance and capacitor where are supposed to be linear, time invariant and frequency independent, [13].

The average output voltage V_c is given by:

$$V_c = \frac{V_{PV}}{1-\alpha} \tag{14}$$

where

$L = 290\mu H$, $C1 = 250\mu F$, $C2 = 330\mu F$, $R = 35\Omega$ and the PWM frequency $f_{PWM} = 10kHz$.

5. MPPT scheme

The MPPT algorithm used the measured values of the output voltage and/or the output current of the PV module to estimate the duty cycle (D) of the DC–DC converter in order to keep the electrical load characteristics with those of the PV module at the Maximum Power Point MPP, [13].

5.1 Perturb & observe (P&O) algorithm

P&O algorithm is most popular and usually adopted strategy between all MPPT techniques. This algorithm is frequently used for commercial PV module because it is easy to implement and inexpensive, [9, 17].

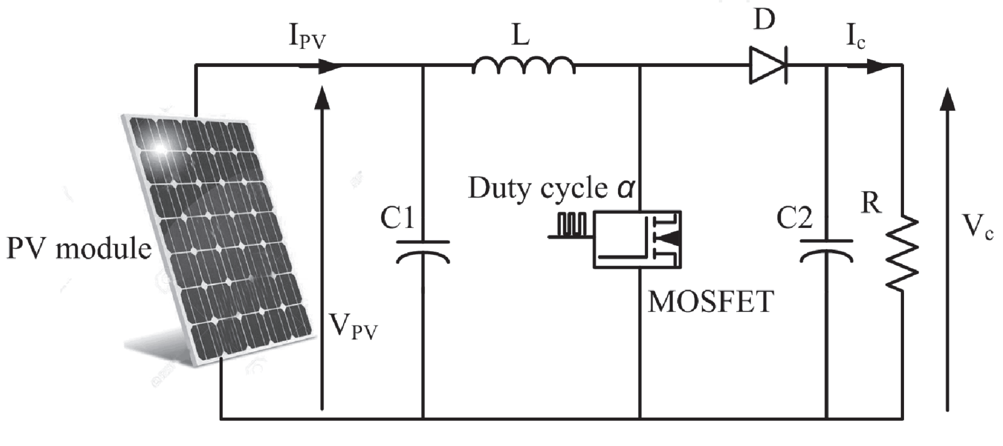

Figure 3.
Boost converter structure.

The P&O method is based on, [15–17]:

- Periodical measuring the PV module voltage $V(k)$ and current $I(k)$ to calculate the output power $P(k)$;
- Perturbing (increasing or decreasing) the switching duty cycle (D) of the Boost converter to change the operating point. In this study a slight perturbation $(\Delta D = 0.01)$ is introduced in the system.
- Observing the output power variation $\Delta P = P(k) - P(k-1)$:
    - If $\Delta P > 0$, the Maximum Power Point MPP will be approached, therefore the perturbation should be kept the same for the following stage;
    - Otherwise the perturbation should be reversed.
- This process is repeated until the MPP is reached.

Figure 4 presents the P&O algorithm implemented in Matlab/Simulink®.

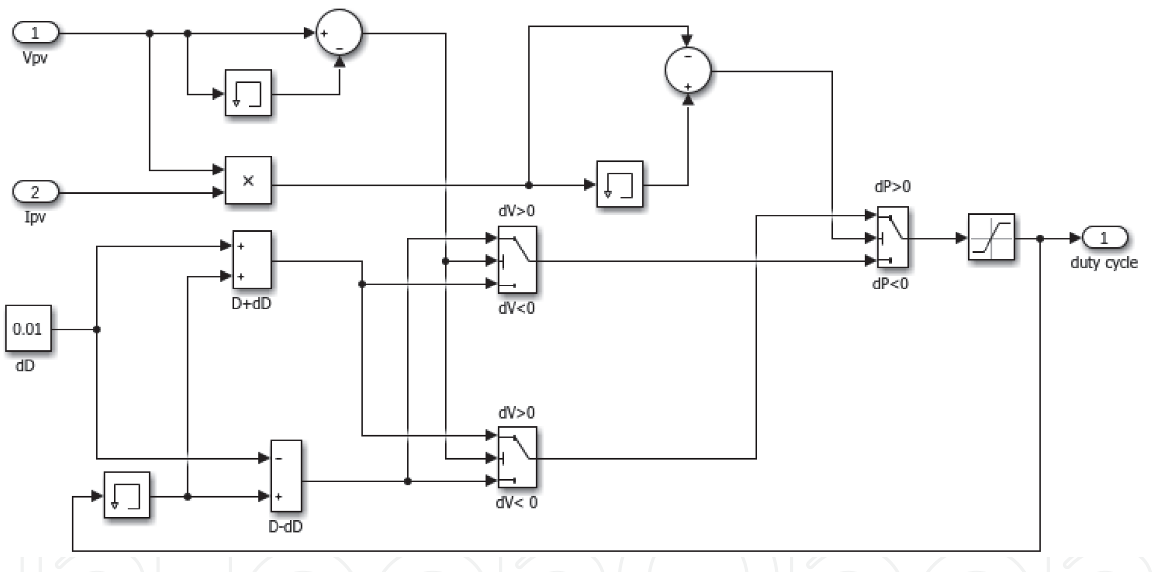

Figure 4.
P&O algorithm in MATLAB/Simulink®.

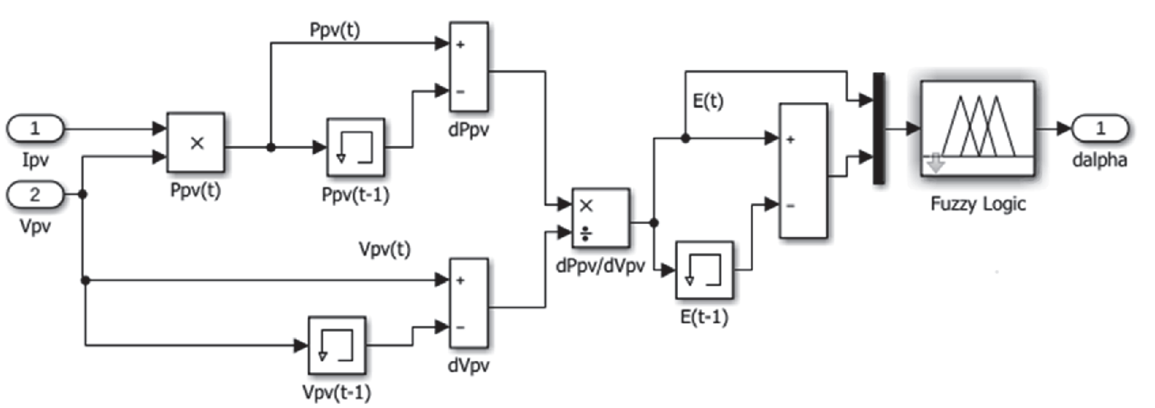

Figure 5.
Fuzzy logic algorithm in MATLAB/Simulink®.

5.2 Fuzzy logic (FL) algorithm

The FL algorithm checks the output power value of the PV module at each instant (t) and then calculates the power variation $\left(dP/_{dt}\right)$according to the voltage variation, [16, 18].

The fuzzy logic algorithm generally consists of three stages: the fuzzification, the rules and the defuzzification, [16, 18].

Figure 5 illustrate the fuzzy logic (FL) algorithm implanted in Simulink environment.

6. Results and discussion

6.1 MPPT control performance under the concentration conditions

In the first part of this subsection, the concentration ratio is fixed to C = 1x. For this report, the PV module temperature simulated by the software Matlab/Simulink® is equal to T = 53.75 °C.

The simulation results of the CPV system using two different techniques (P&O and FL) are presented successively by the **Figures 6–8**:

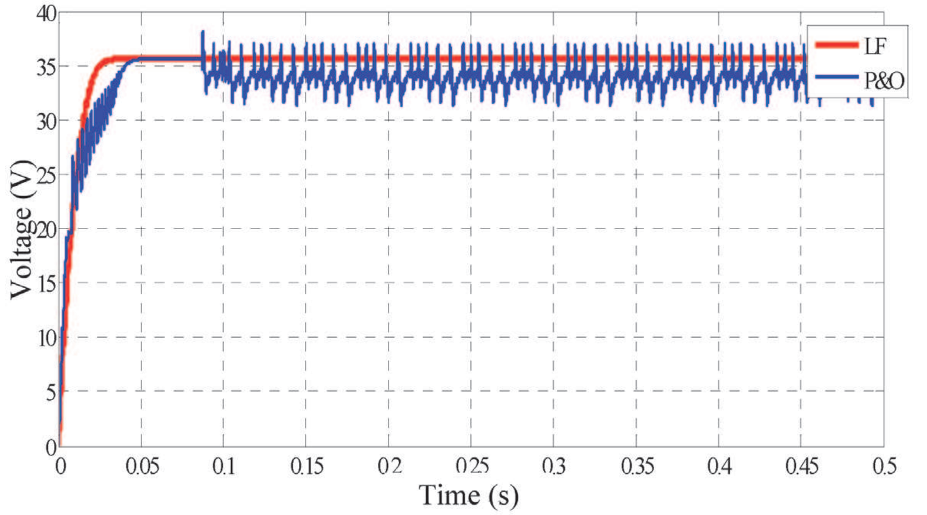

Figure 6.
Output voltage using the MPPT control (P&O and FL) for C = 1x and T = 53.75°C.

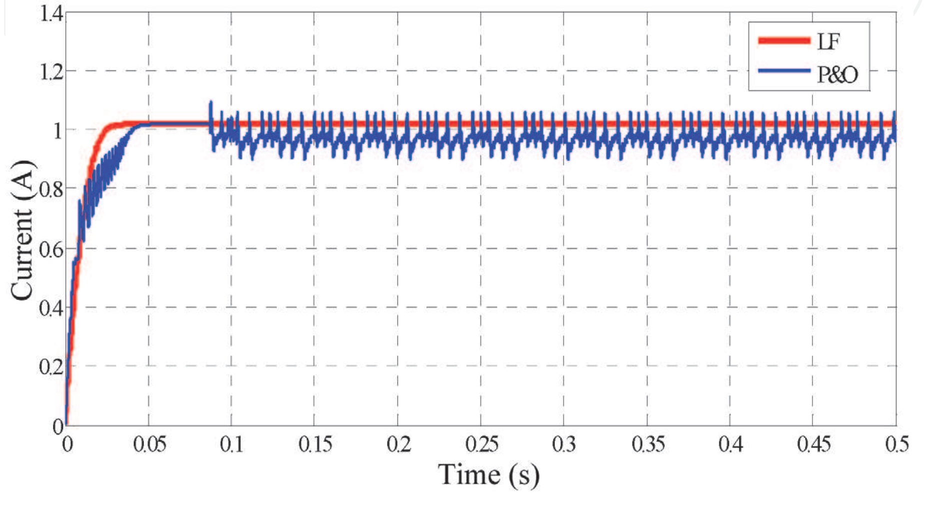

Figure 7.
Output current using the MPPT control (P&O and FL) for C = 1x and T = 53.75°C.

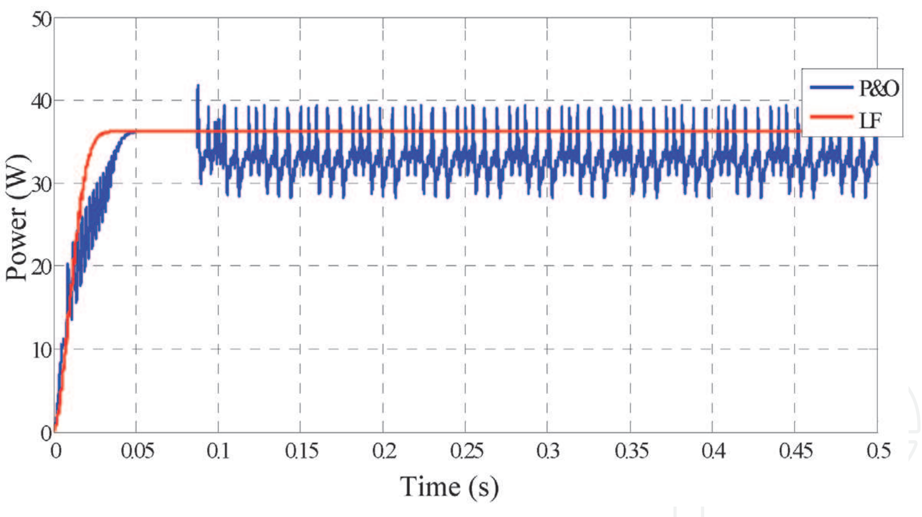

Figure 8.
Output power using the MPPT control (P &O and FL) for C = 1x and T = 53.75°C.

Concentration report MPPT		C = 1x	C = 2x	C = 3x
Simulated temperature		*T = 53.75°C*	*T = 87.5°C*	*T = 121°C*
Fuzzy logic (LF)	I_s (A)	0.97	1.088	1.126
	V_s (V)	33.72	38.08	39.39
	P_s (W)	32.48	41.42	44.34
	η_{mppt}(%)	96	96	96
Perturbation and observation (P&O)	I_s (A)	0.963	1.088	1.126
	V_s (V)	33.71	38.08	39.39
	P_s (W)	32.46	41.42	44.34
	η_{mpp} (%)	85.8	96	96

Table 3.
V_s, I_s, P_s and η_{mppt} variation of the MPPT control (P&O and FL) as a function of the concentration ratio.

Then, the CPV system performance parameters, the output voltage V_s, the output current I_s, the maximum output power P_s and the efficiency η_{mppt} for different values of the solar concentration ratio (1x, 2x, 3 x) are determined in **Table 3**.

From the results obtained, it can be seen that the "Fuzzy Logic" control does not exhibit oscillations at the steady state of the current curve I_s, the voltage V_s and the power P_s and that the response time of this technique is fast. While, the P&O control exhibits several disturbances due to climate change (temperature and concentration) and results in a longer response time than the other technique. For a concentration ratio C = 1x, the efficiency of the CPV system using the FL control is equal to 75% while the efficiency of the CPV system using the P&O control is equal to 74.1%. For a C > 1x concentration ratio, the efficiency of the CPV system using both FL and P & O controls is stabilized by up to 60%.

So, we can deduce that the FL control performs better than the P&O control.

The characteristics (I-V) and (P-V) of the CPV system using the P&O and LF control are represented successively in **Figures 9** and **10** for different values of the concentration ratio solar (1x, 2x, 3 x).

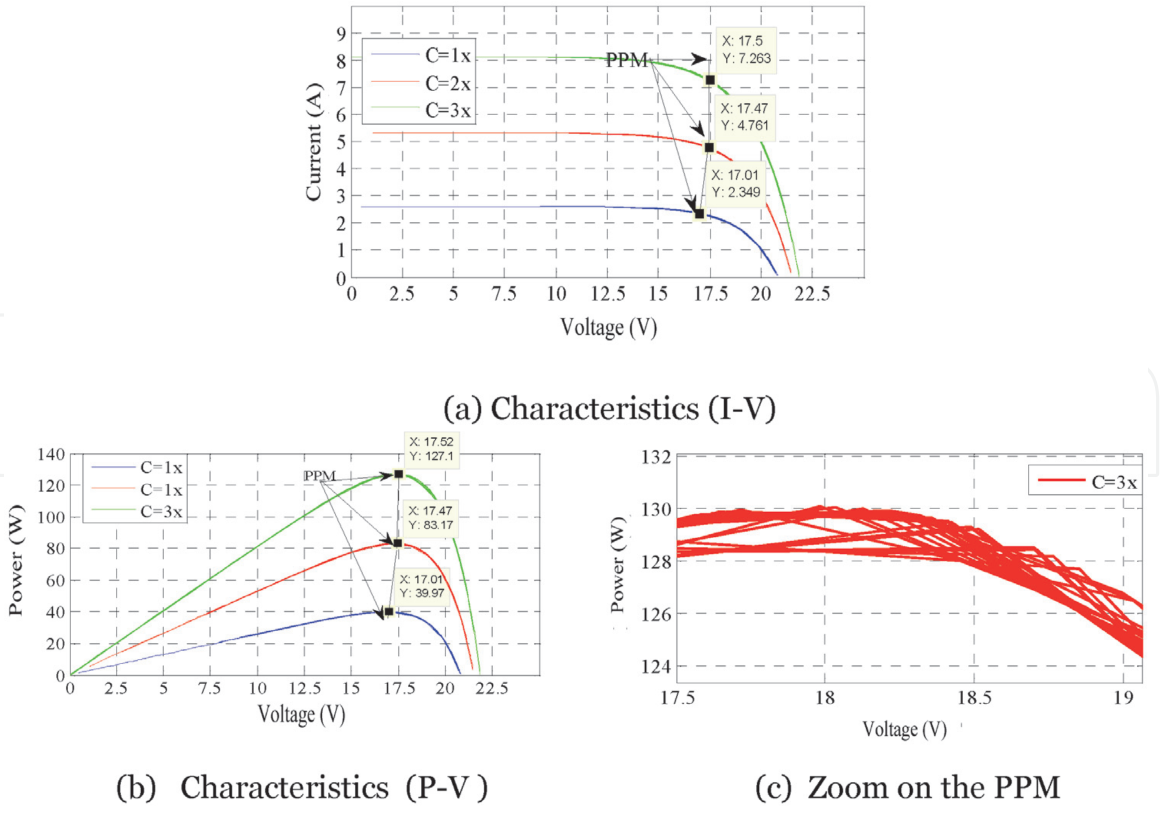

Figure 9.
Characteristics (I-V) and (P-V) of the CPV system using the P&O control under different solar concentration values. (a) Characteristics (I-V). (b) Characteristics (P-V). (c) Zoom on the PPM.

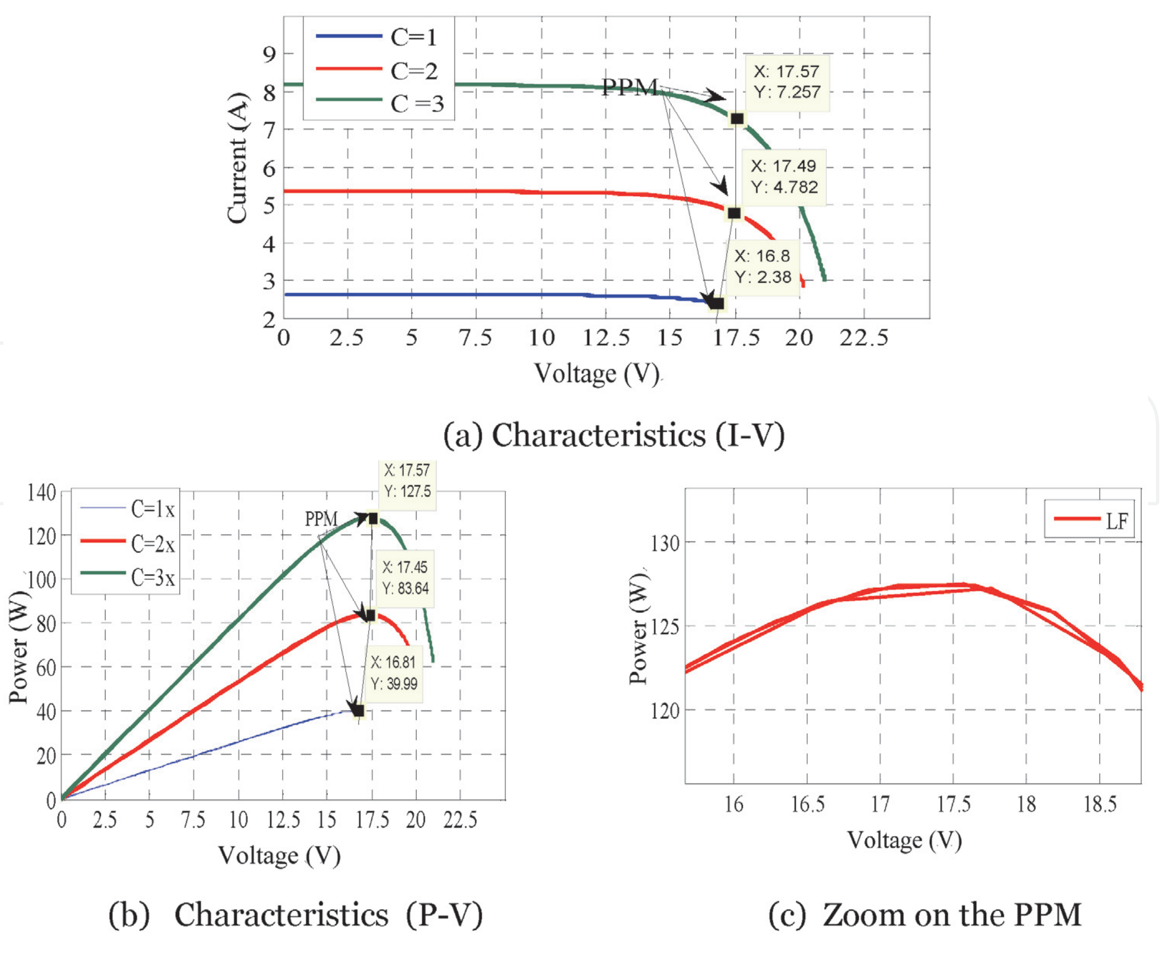

Figure 10.
Characteristics (I-V) and (P-V) of the CPV system using the FL control under different solar concentration values. (a) Characteristics (I-V). (b) Characteristics (P-V). (c) Zoom on the PPM.

As shown in **Figures 9** and **10**, it can be seen that the PV module output (I-V) and (P-V) characteristics strongly influenced by the variations in metrological conditions (temperature and concentration) for both control P&O and FL. It should be noted that the maximum power point MPP of the PV module is also influenced by the concentration ratio C and the temperature T.

When the temperature varies, the P&O control shows the existence of strong oscillations around the maximum power point, **Figure 9(c)**. Due to these oscillations around this point, the CPV system shows energy losses.

Contrariwise, during a temperature variation, and using the fuzzy logic control, there are weak oscillations around the MPP which limits the power losses, **Figure 10(c)**.

6.2 MPPT control performance with the improve CPV system

In this section, initially, we maintained the same model under the concentration conditions implemented under Matlab / Simulink® software by setting the temperature at 35°C. Secondly, we varied the solar concentration ratio C, in a range of (2x to 10x), to study the performance of the two MPPT controls used in the CPV system.

6.2.1 P&O control performance

From the output power curves $P_s(t)$, **Figure 11**, it is noted that the increase in concentration causes an increase in power. But also for each power curve, we obtain two parts:

- ***Regime1:*** it is the transient regime of the power presents enormous peaks. The transient state indicates the control speed.

- ***Regime2:*** the steady state shows the stability of the power over time.

The output power signal P_s stabilizes in a reduced response time, e.g. for C = 3x, Tr = 0.0106 s. This shows that the FL control performs well its role which is the

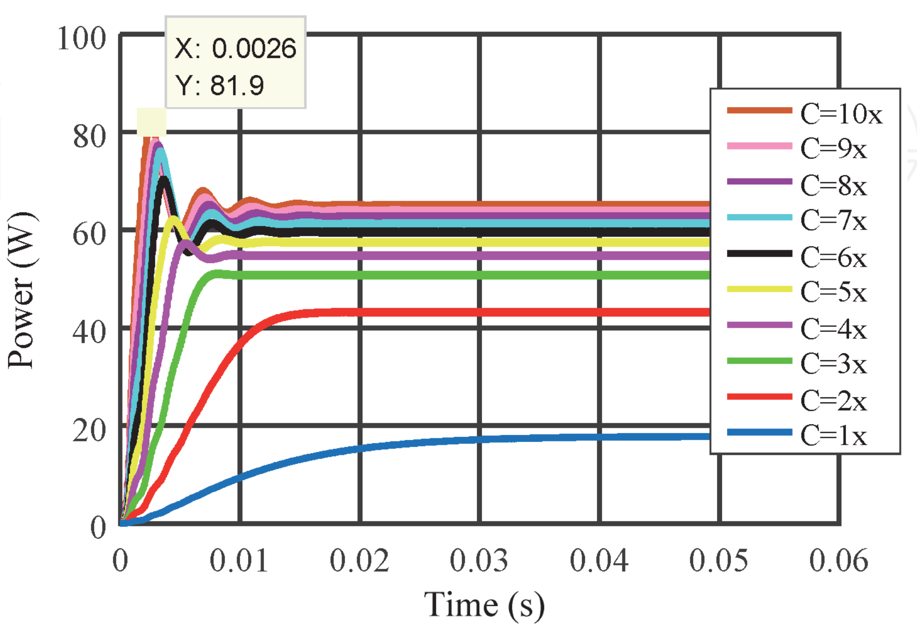

Figure 11.
CPV system output power under the concentration conditions at a constant temperature (35°C) and with P&O control.

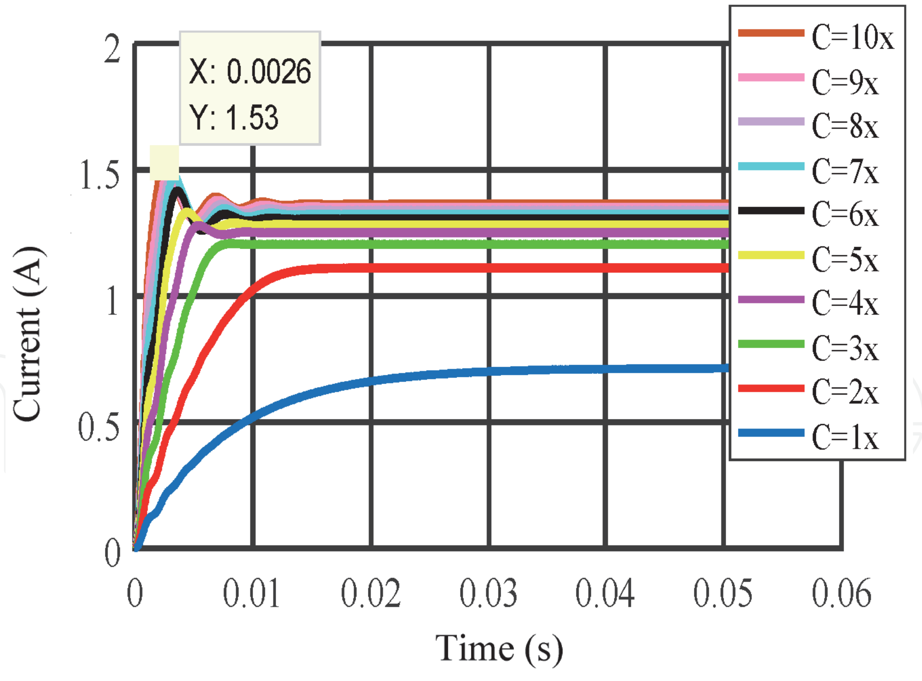

Figure 12.
CPV system output current under the concentration conditions at a constant temperature (35°C) and with P&O control.

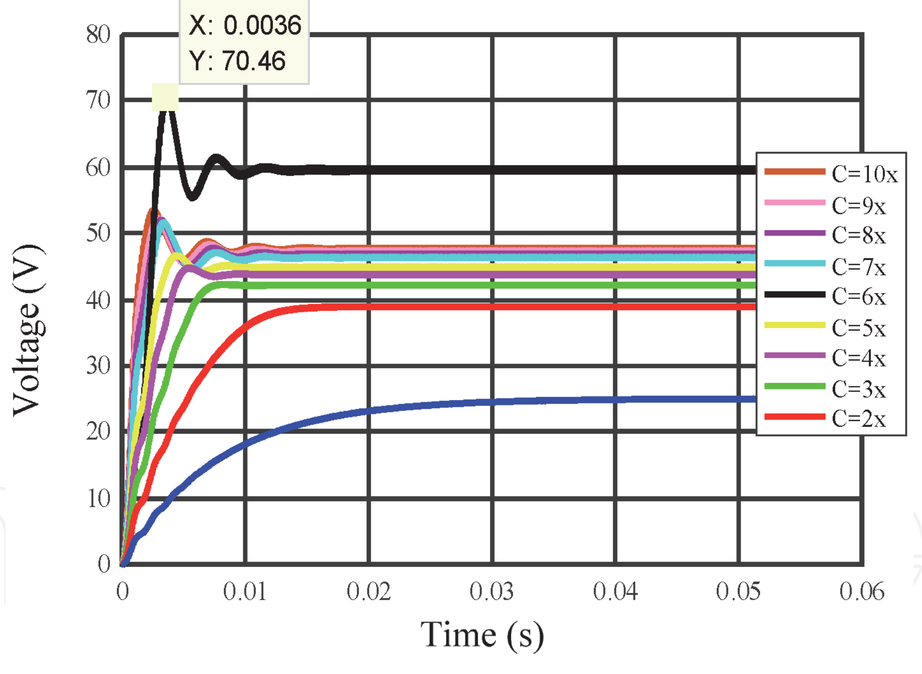

Figure 13.
CPV system output voltage under the concentration conditions at a constant temperature (35°C) and with P&O control.

tracking of the maximum power point on the one hand and secondly, the CPV system output signal is stable.

When C = 10x, the P_s curve has the largest peak (P_s = 65.23 W).

According to **Figures 12** and **13**, the output current I_s and the output voltage V_s have a transient region and a permanent region. Similarly, in the previous results, we note that the transient regime has large peaks.

The Boost converter that ensures the electrical energy transit between the PV module and the resistive load, it is characterized by their impedance which creates voltage drops (disturbances of the duty cycle) and energy losses.

Parameters	C = 1x	C = 2x	C = 3x	C = 4x	C = 5x	C = 6x	C = 7x	C = 8x	C = 9x	C = 10x
Current I_s (A)	0.715	1.114	1.207	1.253	1.284	1.307	1.326	1.341	1.354	1.365
Voltage V_s (V)	25.04	38.98	42.24	43.87	44.95	45.76	46.4	46.93	47.38	47.78
Power P_s (W)	17.92	43.41	50.98	54.99	57.73	59.82	61.51	62.93	64.15	65.23
MPPT efficiency (%)	53	56	59	63	65	67	69	70	72	73
Response time	0.058	0.0173	0.0106	0.0106	0.0121	0.0149	0.015	0.016	0.0196	0.0174

Table 4.
The characteristic quantities of the "SOLKAR 36 W" module under the concentration conditions at a constant temperature (35°C).

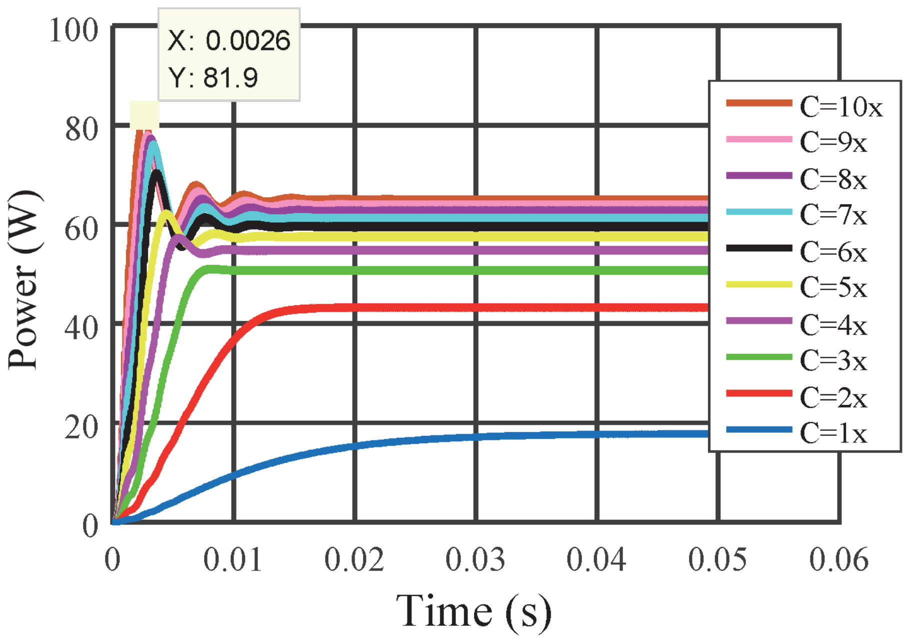

Figure 14.
CPV system output power under the concentration conditions at a constant temperature (35°C) and with FL control.

Strong currents and impedance can cause long-term oscillations.

The simulation results show that this system can adapt to a resistive load (R = 35 Ω). Indeed, it can give a fast response and a good transient performance, insensitive to changes in external disturbances.

Table 4 summarizes the PV module characteristic parameters under the concentration conditions at a constant temperature (35°C): the output voltage Vs, the output current Is, the output power Ps, the MPPT efficiency η_{mppt}, and the response time T_r.

6.2.2 Fuzzy logic (FL) control performance

From **Figures 14–16**, we note that the results obtained by the FL control are similar to those obtained by the P&O control, the same transient regime which we find the peaks and the same steady state which is stable and the oscillations are gone.

It can be seen that the new configuration of the CPV system has improved the performance of the P&O control. We can therefore deduce that the appearance of oscillations in the old CPV system is due to the rise in temperature. By setting this parameter, it was possible to stabilize the output signals of the system.

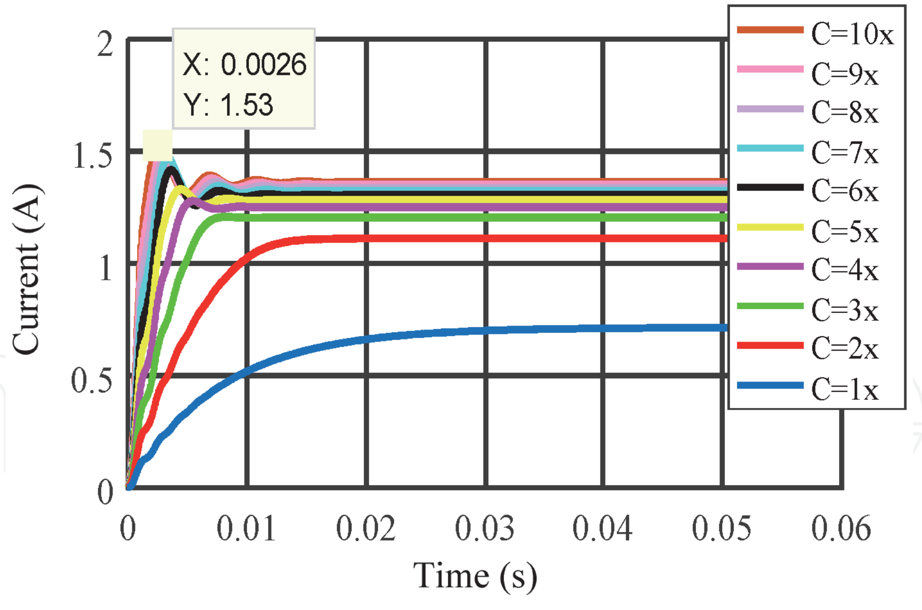

Figure 15.
CPV system output current under the concentration conditions at a constant temperature (35°C) and with FL control.

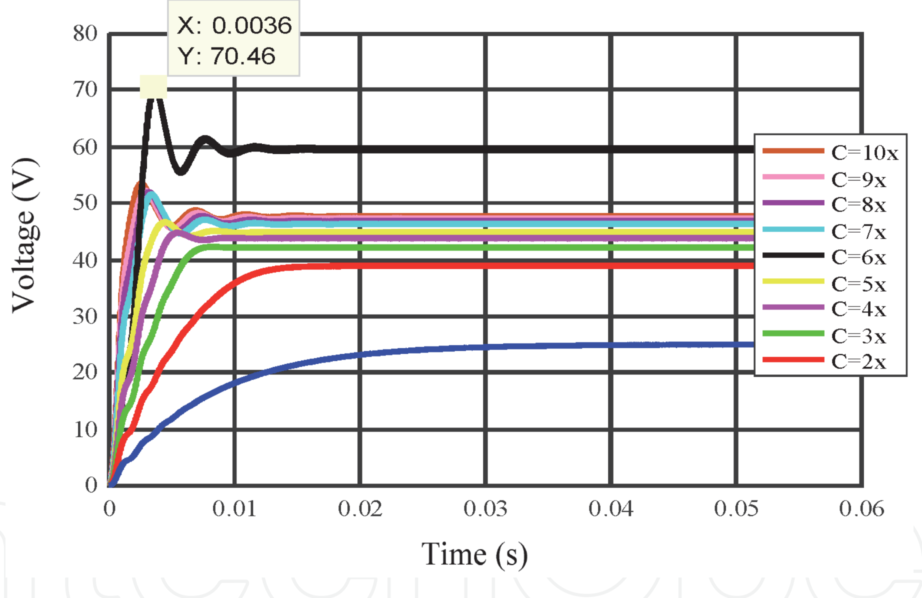

Figure 16.
CPV system output voltage under the concentration conditions at a constant temperature (35°C) and with FL control.

MPPT Type	Stability	Sensors number	Response time (Convergence time)	Digital or analog	% Yield
LF	Stable	1 current 1 voltage	0.0106	digital	73
P&O	Stable	1 current 1 voltage	0.0106	Analog Or Digital Or Both	73

Table 5.
The performances of the two techniques "P&O" and "FL".

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The following **Table 5** shows the performance of two MPPT techniques P&O and FL for a CPV system with a cooling system:

From **Table 5**, it can be concluded that the P&O control in the CPV system with a cooling system becomes more interesting than the FL control. Indeed, these two controls have the same evolution of the output signals (P_s, V_s, I_s), same response time, same transient regime and same performance but the advantage of the P&O control and that its practical implementation is simpler than the FL control.

The P&O technique has the following performances:

- Low implantation cost
- the ease of its implementation
- no need for precise inference parameters

In return, the fuzzy logic control in the CPV system has disadvantages such that:

- High implantation cost
- the complexity of its implementation
- Need precise inference parameters.

7. Conclusion

This work aims to present the principle of a CPV system, thus to study the modeling of a PV module placed at the focus of a parabolic concentrator. Then, we simulated this CPV system in a Matlab/Simulink ® environment under different conditions of temperature and concentration ratio. Finally we showed the performance of the two MPPT commands (P&O and FL).

Simulation results showed that both MPPT methods (P&O and FL) were successful in continuing and reaching the PPM peak power point although disturbances due to temperature and concentration changes. As well as the control by fuzzy logic causes the best performance in terms of response time, stability and accuracy.

In the second part of this chapter, we improved the CPV system configuration by adding a cooling system and setting the temperature to 35°C. The simulations results in these new conditions show that the performances of the two MPPT P&O and FL controls are identical and the oscillations are thus due to the rise in temperature.

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Conflict of interest

The authors declare no conflict of interest.

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