Comparative study of the MPPT control algorithms for photovoltaic panel

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Abstract:

The load supply from a photovoltaic generator is still the subject of many studies. In this document, we will look to the modeling of the photovoltaic system and the presentation of maximum power point tracking algorithms (MPPT). The purpose of this paper is to extract the maximum power point at which the photovoltaic system can operate optimally.

The most common MPPT techniques that will be studied are: "Perturbe and Observe" method (P&O), Conductance Increment method (CI) and Fuzzy Logic Control (FL).

Finally, we will simulate via Matlab the algorithm of each method in order to obtain the performance of each one.

Keywords:

MPPT, Photovoltaic Panel, P&O, CI, Fuzzy Logic

1. Introduction

Being one of the most important means of generating electricity, photovoltaic energy constitute an important source of energy that every country in the world, having a high solar density, seek to develop. Moreover, this energy remains the most "elegant" since it is silent; non-polluting; inexhaustible and easily integrated into housing.

On the other hand, it is known that the production of photovoltaic energy is nonlinear and varies depending on factors such as the illumination, the temperature and the age of the panel itself. Therefore, operating point of the photovoltaic panel (PV) is often not coinciding with the maximum power point.

So, the challenge is to, constantly, determine the maximum operating point of the photovoltaic panel in order to assign a maximum power to the load at all times. Indeed, the power generated by a photovoltaic panel depends on its operating voltage. Thus, the characteristic curves V-I and V-P specify a single point where the maximum power is delivered.

This method is called MPPT (Maximum power point tracking). [1] [2]

To increase the efficiency of this method, we insert a regulation for the photovoltaic panel; that makes it a "follower" and allows us to optimize the production of electricity. There are several methods of finding the maximum power point. These depend on the type of sensors used, speed, efficiency, price and accuracy. The purpose of this article is to synthesize the optimal MPPT method to reach the maximum point of operation while minimizing any eventual loss of power.

This article will start, in section 2, with a description of the photovoltaic generator including the Boost convertor. Then, in section 2, methods of search for the maximum point ("Perturbe and Observe" (P&O), Conductance Increment (CI) and Fuzzy

Logic Control (FL)) will be highlighted. At the end, simulations, results and discussions will be detailed in section 4, followed by conclusions.

2. Photovoltaic system

A photovoltaic generator (PVG) is composed of several photovoltaic cells mounted in series and/or in parallel. It is composed also of a conversion system (DC-DC converter), MPPT controller, and storage device (DC load). This set is called a photovoltaic system.

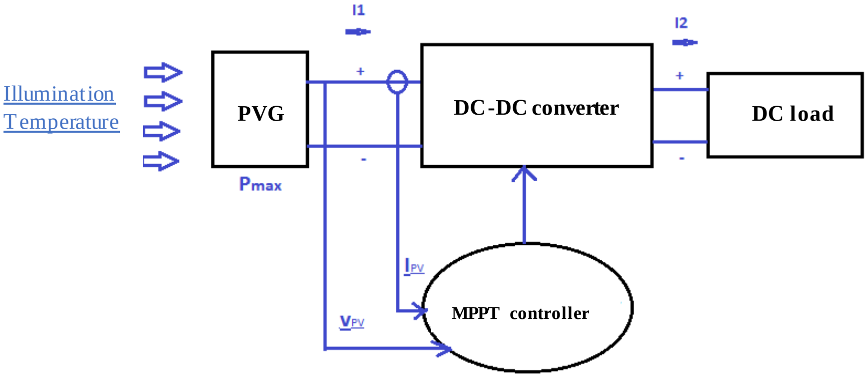

Figure 1. Photovoltaic conversion elementary chain controlled by an MPPT control

2.1 Model of photovoltaic panel

A photovoltaic panel is the result of conversion of energy that photons carry from light when they are in contact with suitably processed semiconductor materials.

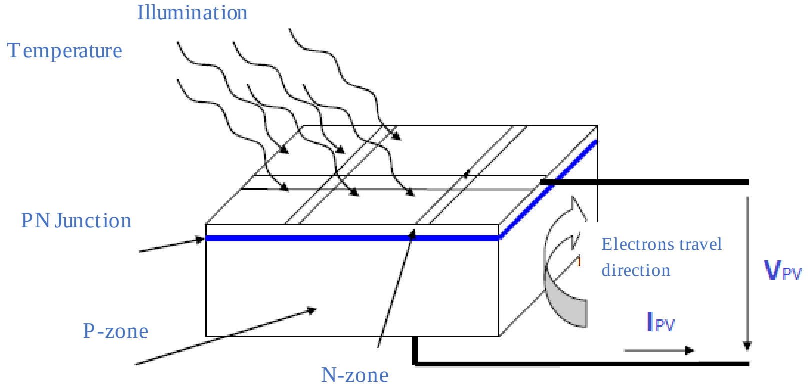

Figure 2. Cross section of a photovoltaic cell

According to Figure 2, when the incident light communicates energy to the semiconductor's electrons, some of them exceed the potential barrier. They are thus expelled to an external circuit.

Electrically, each cell is modeled as the following Figure:

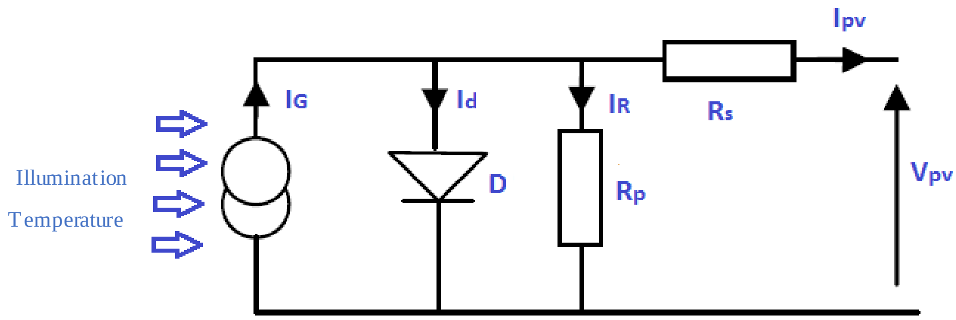

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Figure 3. Electrical model of a photovoltaic cell

R_s: Line contact resistance

R_p, I_R: Resistance and leakage current due to diode and effects on the junction

I_G: Current created by absorbed solar radiation, this current is practically worth the short-circuit current Icc.

(I_{PV}, V_{PV}): Photovoltaic panel characteristics *[7]*

$$I_{PV} = I_G - I_R - I_d$$

According to the Shockley equation; we have:

$$I_d = I_0 (\exp(e.V_d/K.T) - 1)$$

And:

$$V_d = (K.T/e).\ \ln(I_d/I_0 + 1)$$

With:

I_0: reverse saturation current

V_d: The diode's terminals voltage

e: charge of electrons

K: Boltzmann constant

T: Junction's temperature

Also, when the circuit to the terminals of the cell is opened, we can write:

$$V_{0c} = (K.T/e).\ \ln(I_{cc}/I_0 + 1)$$

The parallel current which goes through the Rp resistance is:

$$IR = V_d/Rp$$

Taking into account the effect of the series resistance, we have:

$$V_d = V + Rs.\ I$$

The final equation of photovoltaic panel model is:

$$I = Icc - I_0 (\exp(e.[V + Rs.\ I]/K.T) - 1) - ([V + Rs.\ I]/ Rp)$$

In this paper, we will be based on a photovoltaic panel composed of 12 solar cells in series. The characteristics of the cell are:

Tableau1. Characteristics of the PV cell used

Illumination	1000 W/m²
Temperature	25°C
Short circuit current (Icc)	7,34 A
Short circuit voltage (V0c)	0,6 V
Number of cells per module	12

On the software Matlab Simulink interface, we can explicit the model of a photovoltaic panel and deduct then the characteristic of the current and the power based on the voltage as follows:

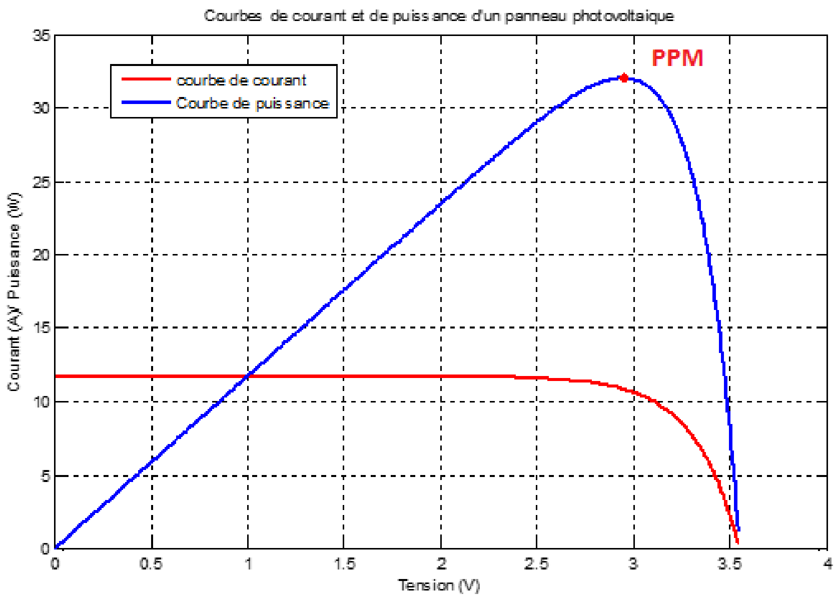

Figure 4. Characteristics of Power-Voltage (P-V) and current-voltage (I-V) of a photovoltaic panel

The power maximum point MPP differs depending on the temperature and illumination.

Indeed, on our model, here are the curves of current corresponding to illumination of 1000 W/m², 600 W/m² and 300 W/m², for a steady temperature of 25° c.:

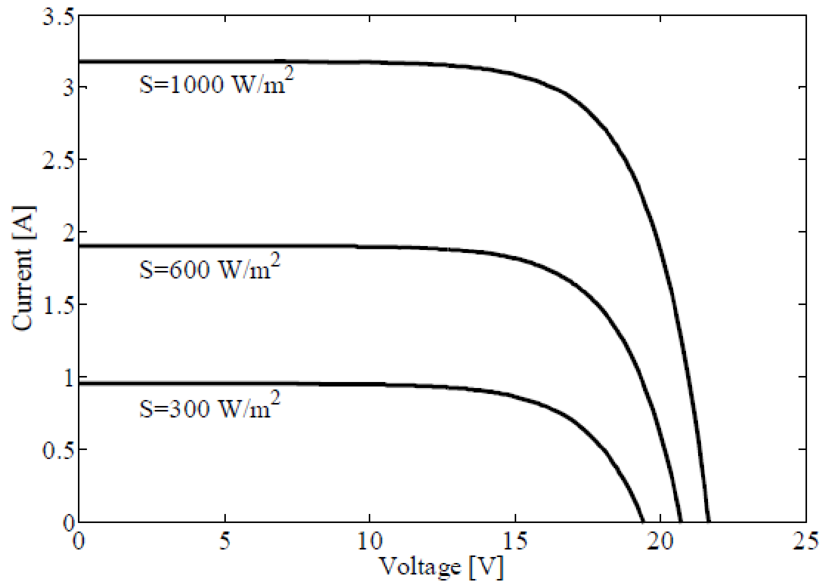

Figure5. Power curves for PV panel under different light levels

On the other side, when we fix the illumination at the value of 1000 W/m² and change the temperature, here is the change on the power curve and the MPP for respective temperatures of 300 K, 330 K and 360 K.

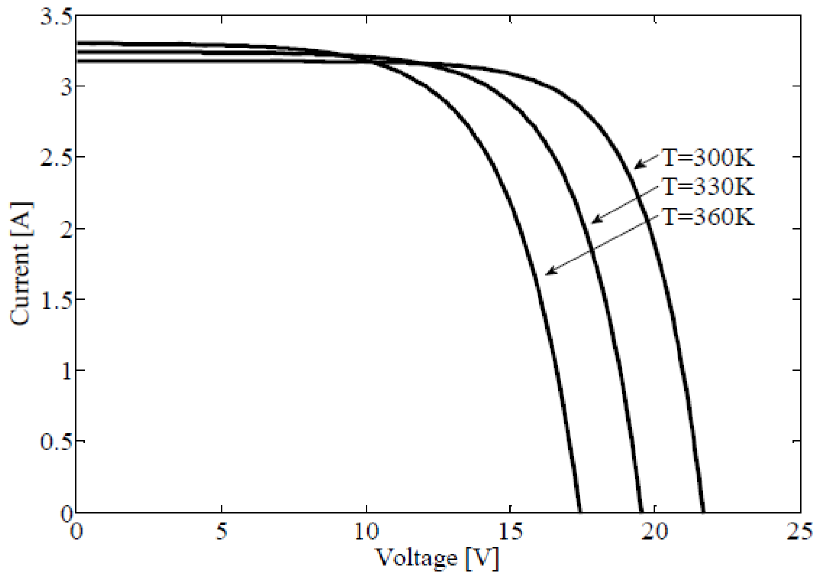

Figure 6. Power curves for a PV panel under different values of temperatures

2.2 Conversion system

In the conversion system, it is based on a BOOST type DC - DC converter.
Figure 7 shows the electrical structure of this converter. The purpose of it is to realize an adaptation lift source-load, which means between input and output voltage (Ve and Vs). *[7]*

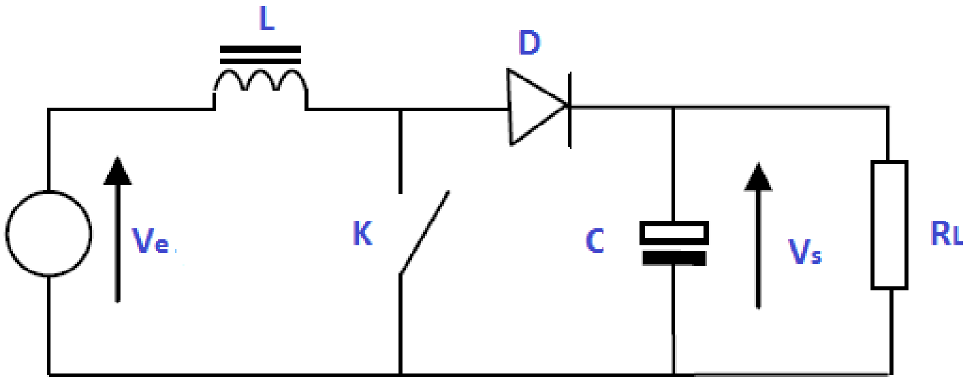

Figure7. Electric structure of the BOOST converter

At time t = 0, the transistor is closed.
For a time t between 0 and αT, we have:

$$Ve = L\ di/dt$$

And so:

$$i(t) = Ve/L\ .t + I_1$$

The current curve is thus a growing curve based on the value I_1

At the moment αT, the transistor is opened.
For a time t between αT and period T, we have:

$$Ve - Vs = L\ di/dt$$

And so:

$$i(t) = (Ve - Vs)\ /L\ .t + I_2$$

For the BOOST converter, Vs is always higher than Ve. The power curve is decreasing starting from the value I_2.

The curve of the current during period T is as follows:

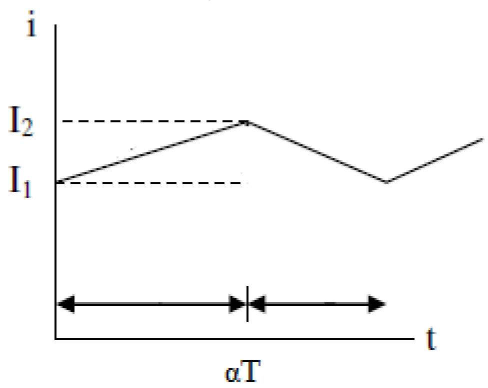

Figure 8. Current curve for a BOOST converter

If the BOOST converter is in continuous conduction and its performance is ideal, we deduce that the adaptation between the source and the load depends on the duty cycle.
Indeed, the voltage Vs can be expressed according to the voltage Ve:

$$Vs = Ve/\ (1-\alpha) \quad \text{and} \quad Is = (1-\alpha)\ Ie$$

By varying the duty cycle α, we can act on the load in such a way to maximize the power delivered by the PV Panel. This is the interest of the MPPT commands.

3. Maximum point research methods

The MPPT regulation method (Maximum power point tracking) system is essential to ensure optimal operation of the photovoltaic system. [1] [2]

Following are the most used methods that will be highlighted in this paper:

- Perturbe and Observe method (P&O)
- Conductance increment method (CI)
- Fuzzy logic method. (FL) [3] [4]

3.1 "Perturbe and Observe" method (P&O):

It is a method based on the permanent variation of duty cycle and power.
Thus, if:

- $dP/dV > 0$, we approach the MPP and the duty cycle variation is maintained in the same direction.
- $dP/dV < 0$, we move away from the MPP and the duty cycle variation is done in the opposite direction.
- $dP/dV = 0$, we are in the MPP.

For this method, there is a compromise between accuracy and speed since the disturbance must be very low so that the power change will not be too important and thus to minimize power losses. [5].

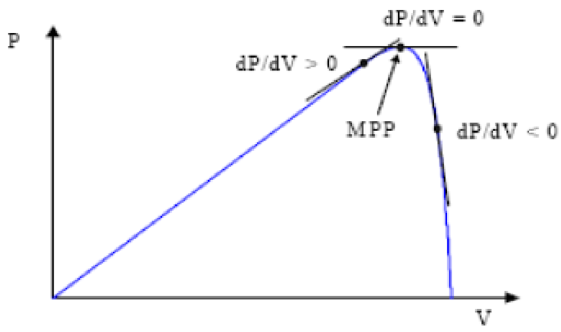

Figure9. Behavior of the power curve under the P&O method

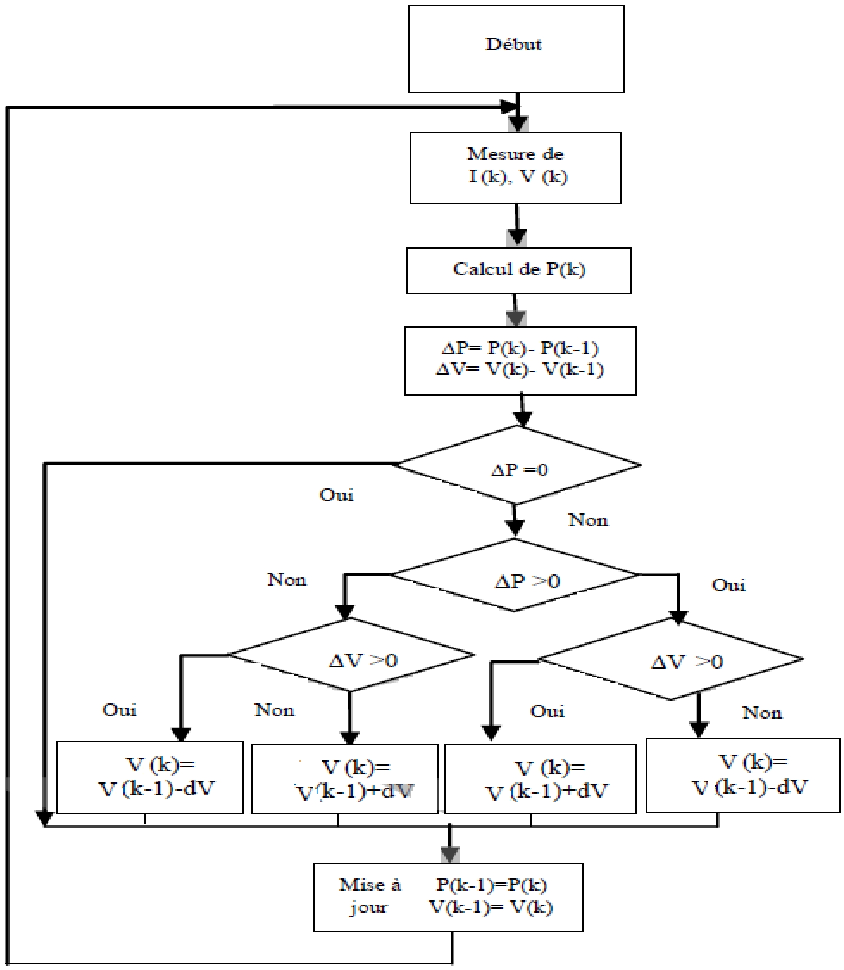

Figure10. P&O Algorithm

3.2 Conductance increment method (CI)

This method acts on the conductance G which is the ratio of current by voltage. [6]

If dG >-G, we decrease the duty cycle.
If dG <-G, we increase the duty cycle.

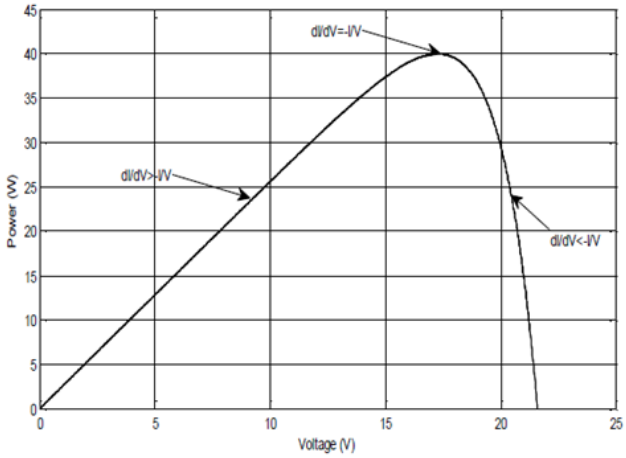

Figure11. Behavior of the power curve under the CI method

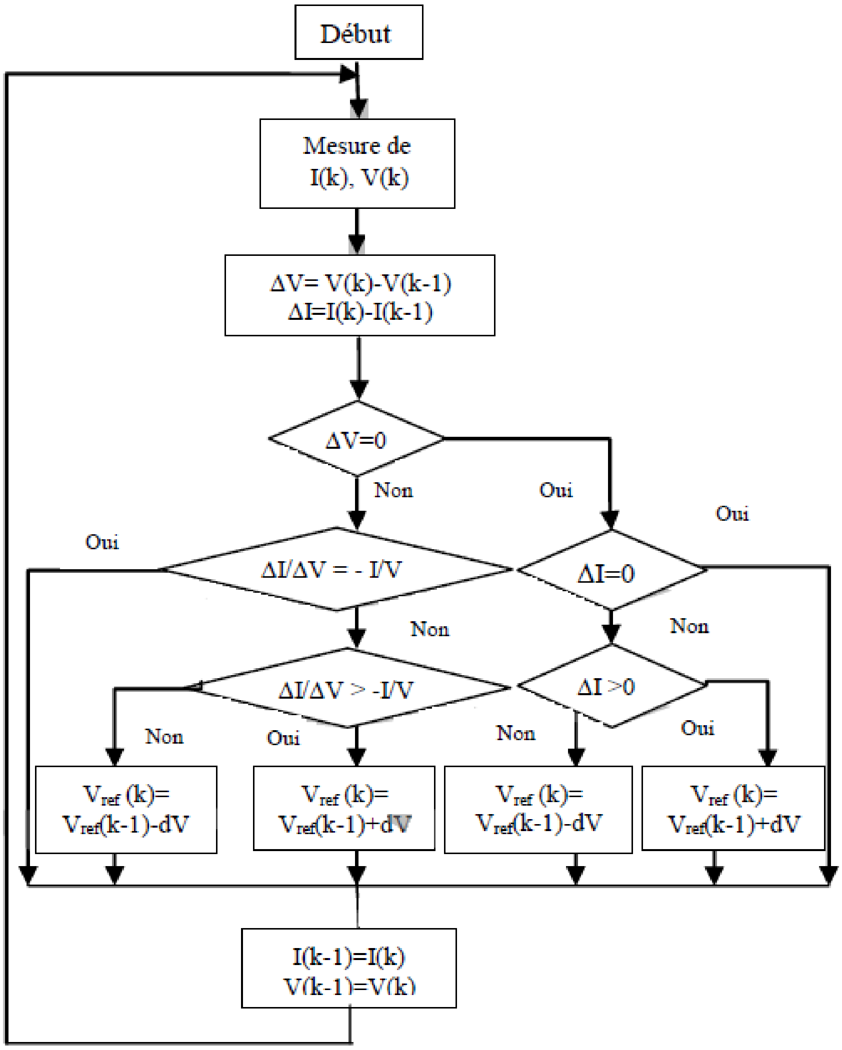

Figure12. CI Algorithm

3.3 Fuzzy logic method

It is a method which is based on the error reduction without the need of accurate knowledge of the mathematical model of the system. *[8]*
This method is based on three essential steps which are: fuzzification, inference and defuzzification.

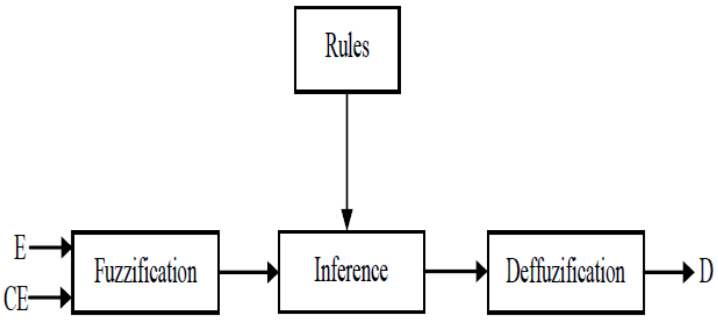

Figure13. Controller steps based on fuzzy logic

The fuzzification's aim is to achieve the conversion of physical variables of entries to fuzzy values. The fuzzy logic controller has two input datas and these are: E which is the error and CE which is the variation of the error. *[8] [9]*

The output is the cyclic ratio dD to which we attribute the following linguistic variables:

NB: Negative Big
NS: Negative Small
ZE: Zero
PS: Positive Small
PB: Positive Big

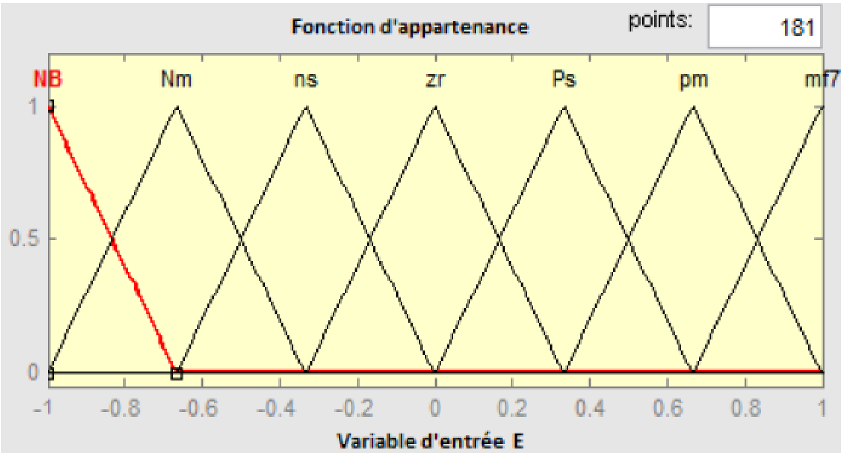

Figure14. Membership function of the error E

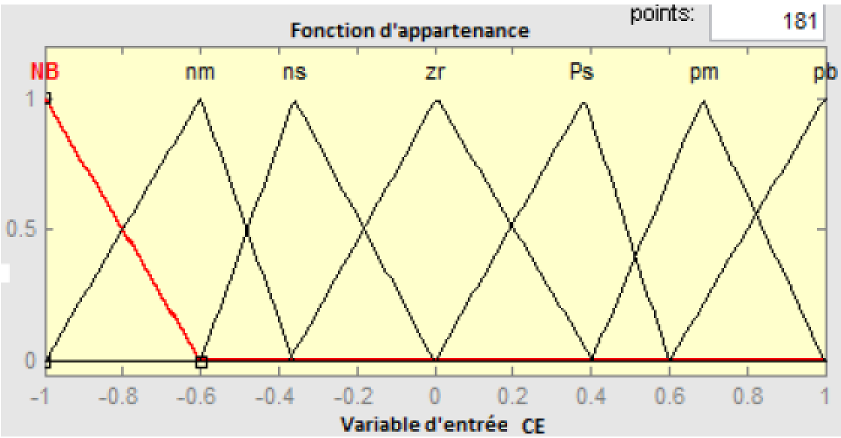

Figure15. Membership function of the error variation CE

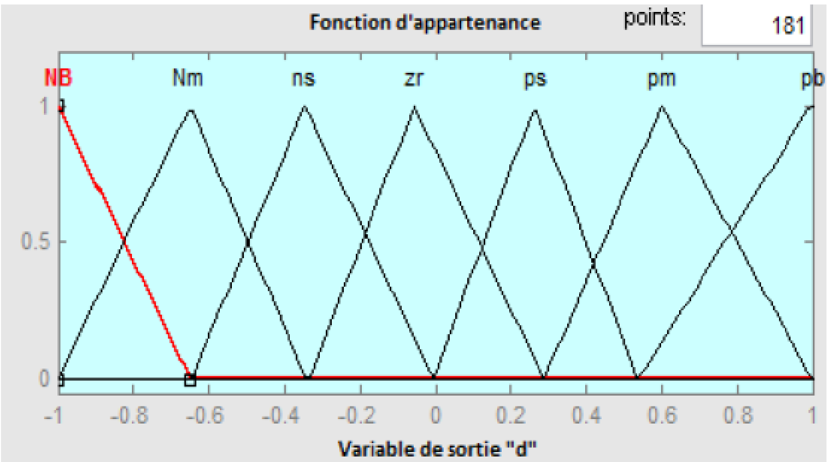

Figure16. Membership function of the cyclic ratio dD

The inference is a step where decisions are made. The aim is to determine the degree of membership of a value to a fuzzy set *[10]* based on fuzzy rules. This is done according to the following inference rules table:

Table 2. Fuzzy rules related to PV controller

E \ CE	**NB**	**NS**	**ZE**	**PS**	**PB**
NB	ZE	ZE	PB	PB	PB
NS	ZE	ZE	PS	PS	PS
ZE	PS	ZE	ZE	ZE	NS
PS	NS	NS	NS	ZE	ZE
PB	NB	NB	NB	ZE	ZE

Let's take the following example:
If **E** is **PB AND CE** is **ZE** then **dD** is **NG**

That means:
If the operating point is **far from** the MPP **to the left,** and if the curve slope change is **practically zero** then the cyclic ratio **dD is very small.**

The inference mechanism that was used is Mamdani's. It consists on using the Max operator for the OR and the Min operator for the AND.

And the defuzzification converts the fuzzy sets into physical variables outputs. Indeed, at the end of the inference, the fuzzy set of output is determined, but is not directly usable to give accurate information. Thus, it is necessary to move from the fuzzy world to the real world.

4. Simulations, results and discussions

We will carry out the simulations of the three previous algorithms for a pair of temperature and illumination of 25° C and 1000 W/m^2.

Here, below, are power and voltage behaviors for each of the three algorithms:

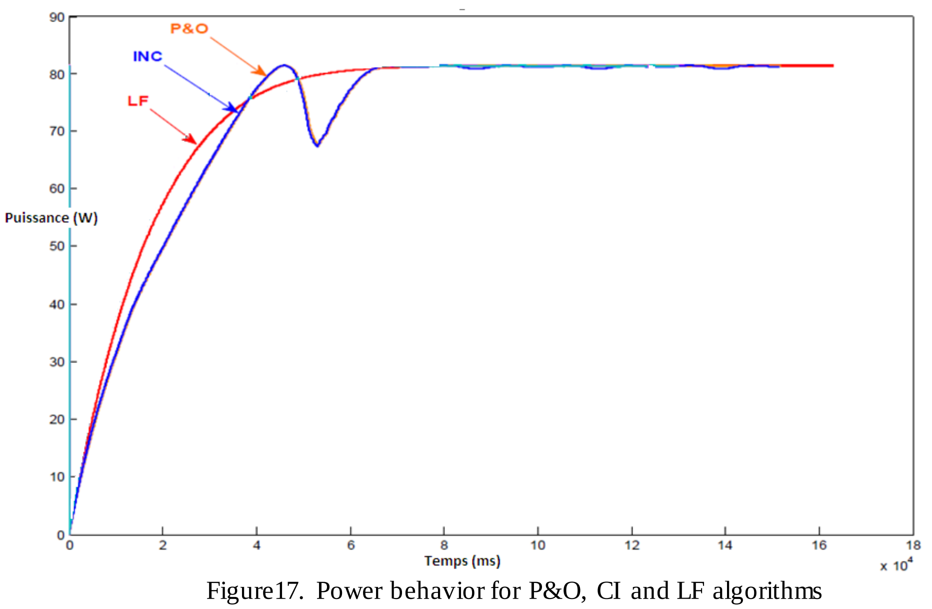

Figure17. Power behavior for P&O, CI and LF algorithms

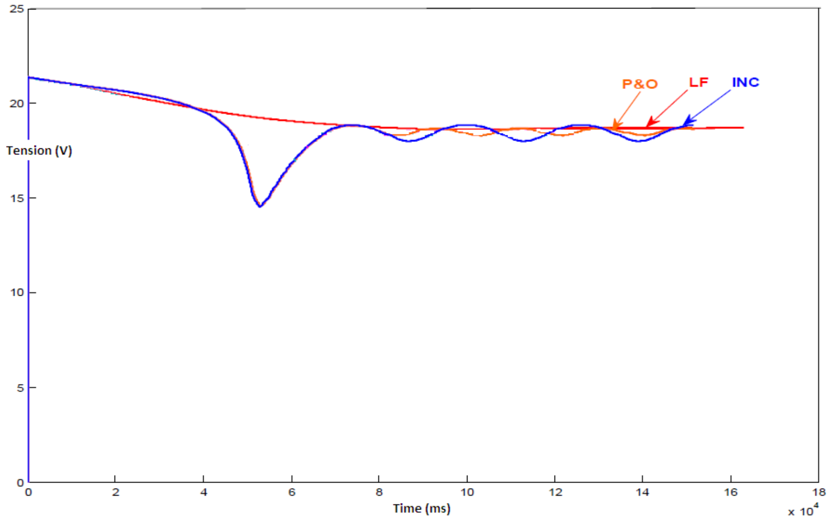

Figure18. Voltage behavior for P&O, CI and LF algorithms

We see that the PV system converges to almost the same values for the 3 algorithms.
Indeed, the three controllers regulate the voltage of the photovoltaic system to produce maximum power.
We can compare the three controllers according to several criteria. The most important are: the speed of convergence, the precision, the type and number of sensors used and the complexity.

The algorithm P&O is a simple algorithm and not complex. However, it presents oscillations around the optimum value, and it is less accurate than the others.
On the other hand, the algorithm CI is clearly an improvement of the P&O. In fact, its development is more complex than the P&O, but it is more accurate and does not have a lot of fluctuations.

Finally, the LF algorithm is the most accurate because it does not have oscillations around the voltage of the MPP and converges quickly. It uses only one current sensor compared to the others that are using two sensors of current and voltage. Contrariwise, it remains very complex to develop. This controller allows to reduce fluctuations and thus reduce the power losses of the photovoltaic panel.

Here is a summary comparison table:

MPPT algorithm	**P&O**	**CI**	**LF**
Complexity	Low	Medium	High
Speed of convergence	Medium	Medium	Very fast
Number of sensors used	2 (current and voltage sensors)	2 (current and voltage sensors)	1 (current sensor)
Precision	Precise	More precise	Very accurate

4. Conclusion

In order to improve the efficiency of a photovoltaic generator, several algorithms of intelligent controls were considered in the industry to search for the maximum operating point. Based on simulations, it is shown that the pursuit of the maximum point is well accomplished in all the three cases, but in different manners which makes one more optimal than the others.

Indeed, the CI and P&O algorithms are the most used in the industry. However, the CI is an improvement of the P&O and gives better results in terms of response and accuracy.

However, the method of fuzzy logic has better performance and better behavior compared to the other two methods in spite of the complexity of its development.

Fuzzy logic method is more flexible for nonlinear systems and allows to find the point of maximum power in a very small time compared to the other methods CI and P&O.
Faced to the different variations, power losses are less, which results in a considerable improvement in the performance of the system.

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