Comparative Study of Algorithms (MPPT) Applied to Photovoltaic Systems

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Abstract- This work presents a theoretical study of maximum power point tracking (MPPT) for photovoltaic (PV) system. The study includes discussion of three MPPT algorithms (the Perturbation and Observation, Incremental Conductance and the Fractional open circuit voltage) and perform comparative tests between them using actual irradiance data. First the PV system with resistive load is discussed, the modelling and the simulation of the PV generator, the DC/DC converter and the three MPPT algorithms are carried out using MATLAB software.

Keywords Maximum Power Point Tracking (MPPT), Photovoltaic System PV, Converter DC/DC.

1. Introduction

Peak power is reached with the help of a dc/dc converter between the PVG and the load by adjusting its duty cycle such that the resistance matching is obtained. Now the question arises how to vary the duty cycle and in which direction so that maximum power is attained [3].

The automatic tracking can be performed by utilizing various algorithms.

Those algorithms are the heart of the MPPT controller. The algorithms are implemented in a microcontroller or a personal computer to implement maximum power tracking. The algorithm changes the duty cycle of the dc/dc converter to maximize the power output of the module and make it operate at the peak power point of the module. Algorithms that can be used are of the following types [2, 4-7]:

- Perturbation and Observation,
- Incremental Conductance
- Fractional open circuit voltage methods.

These algorithms are briefly described and compared in the following section.

2. PV Array

A solar panel cell basically is a p-n semiconductor junction. When exposed to the light, a DC current is generated. The generated current varies linearly with the solar irradiance . The equivalent electrical circuit of an ideal solar cell can be treated as a current source parallel with a diode shown in figure 1.

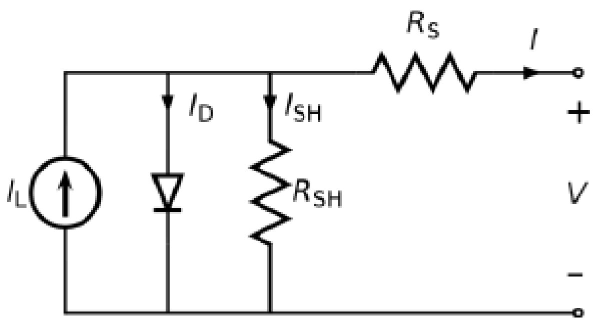

Fig. 1. Equivalent Electrical Circuit of a Solar Cell

The I-V characteristics of the equivalent solar cell circuit can be determined by following equations . The current through diode is given by:

$$I_D = I\ [\ \exp\ (q(V + I\ R_S)/KT)) - 1] \quad (1)$$

While, the solar cell output current:

$$I = I_L - I_D - I_{sh} \quad (2)$$

$$I = I_L - I \left[\exp\left(q(V + IR_S)/KT\right) - 1\right] - (V + IR_S)/R_{sh} \quad (3)$$

Where:

- I : Solar cell current (A)
- I_L :Light generated current (A) [Short circuit value assuming no series/ shunt resistance]
- I_D : Diode saturation current (A)
- q : Electron charge (1.6×10^{-19} C)
- K : Boltzman constant (1.38×10^{-23} J/K)
- T : Cell temperature in Kelvin (K)
- V : solar cell output voltage (V)
- R_s : Solar cell series resistance (Ω)
- R_{sh} : Solar cell shunt resistance (Ω)

3. DC-DC Converter

3.1. Buck Converter

The buck converter can be found in the literature as the step down converter. This gives a hint of its typical application of converting its input voltage into a lower output voltage, where the conversion ratio M = Vo/Vi varies with the duty ratio α of the switch [12].

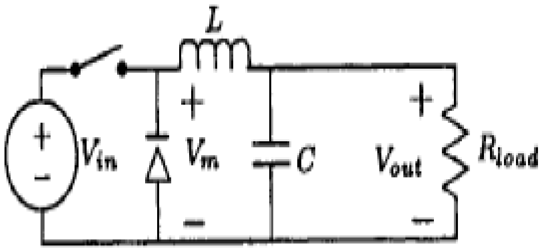

Fig. 2. Ideal Buck Converter Circuit

3.2. Boost Converter

The boost converter is also known as the step-up converter. The name implies its typically application of converting a low input-voltage to a high out-put voltage, essentially functioning like a reversed buck converter [13].

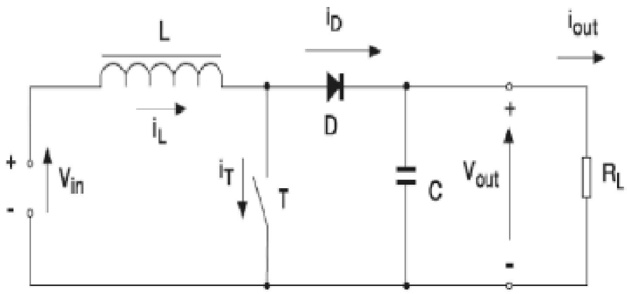

Fig. 3. Equivalent Circuit of a Boost Converter

4. Problem Overview

The problem considered by MPPT techniques is to automatically find the voltage V_{MPP} or current I_{MPP} at which a PV array should operate to obtain the maximum power output P_{MPP} under a given temperature and irradiance. It is noted that under partial shading conditions, in some cases it is possible to have multiple local maxima, but overall there is still only one true MPP. Most techniques respond to changes in both irradiance and temperature, but some are specifically more useful if temperature is approximately constant. Most techniques would automatically respond to changes in the array due to aging, though some are open-loop and would require periodic fine tuning. In our context, the array will typically be connected to a power converter that can vary the current coming from the PV array [4, 9].

5. MPPT Control Algorithms

5.1. Perturb and Observe (P&O)

In this algorithm a slight perturbation is introduce system. This perturbation causes the power of the solar module changes. If the power increases due to the perturbation then the perturbation is continued in that direction. After the peak power is reached the power at the next instant decreases and hence after that the perturbation reverses. When the steady state is reached the algorithm oscillates around the peak point. In order to keep the power variation small the perturbation size is kept very small. A PI controller then acts moving the operating point of the module to that particular voltage level. It is observed that there some power loss due to this perturbation also the fails to track the power under fast varying atmospheric conditions. But still this algorithm is very popular and simple [5].

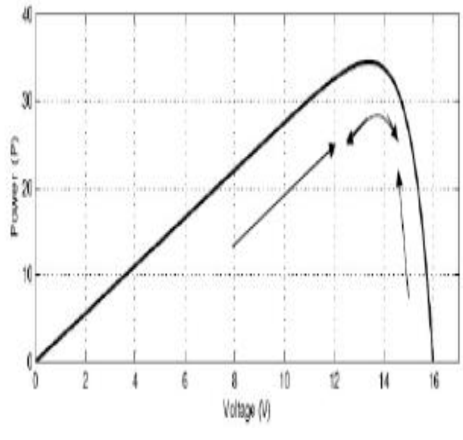

Fig. 4. (a). Graph Power versus Voltage for Perturband Observe Algorithm [5]

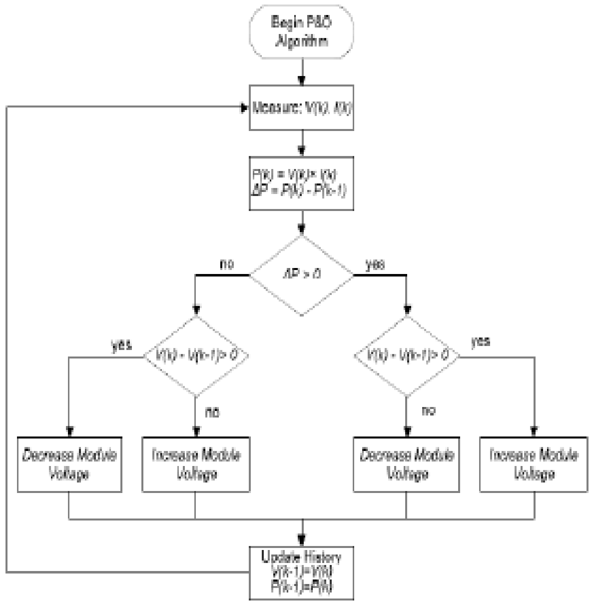

Fig. 4. (b). Perturb and Observe Algorithm

5.2. Incremental Conductance (IC)

The disadvantage of the perturb and observe method to track the peak power under fast varying atmospheric condition is overcome by IC method [5, 13]. The IC can determine that the MPPT has reached the MPP and stop perturbing the operating point. If this condition is not met, the direction in which the MPPT operating point must be perturbed can be calculated using the relationship between dl/dV and –I/V. This relationship is derived from the fact that dP/dV is negative when the MPPT is to the right of the MPP and positive when it is to the left of the MPP. This algorithm has advantages over P&O in that it can determine when the MPPT has reached the MPP, where P&O oscillates around the MPP. Also, incremental conductance can track rapidly increasing and decreasing irradiance conditions with higher accuracy than perturb and observe. One disadvantage of this algorithm is the increased complexity when compared to P&O [5].

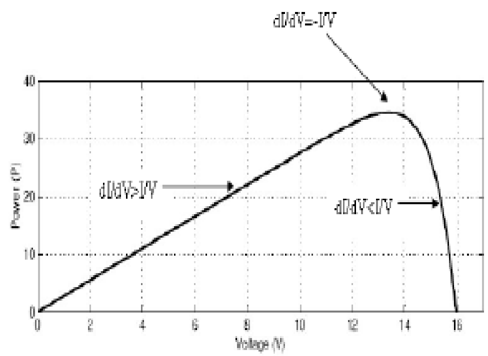

Fig. 5. (a). Graph Power versus Voltage for IC Algorithm

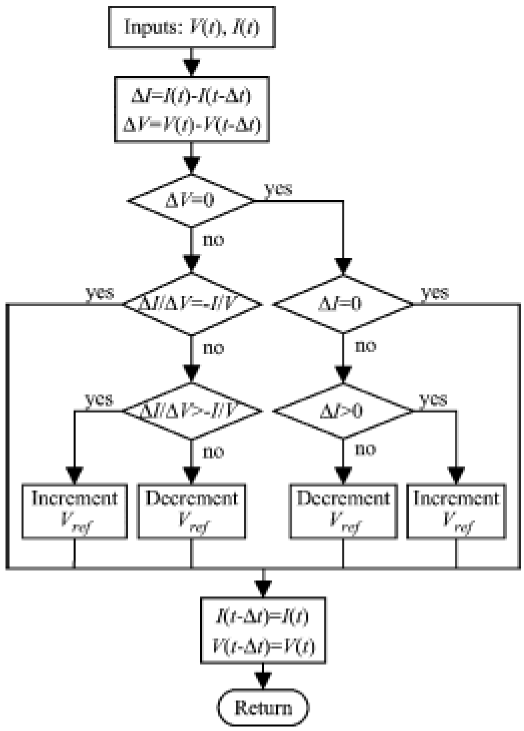

Fig. 5. (b). Incremental Conductance (IC) Algorithm

5.3. Fractional Open Circuit Voltage

This method uses the approximately linear relationship between the MPP voltage (V_{MPP}) and the open circuit voltage (V_{OC}), which varies with the irradiance and temperature [6]:

$$V_{MPP} \approx k_1 V_{OC} \quad (4)$$

Where k_1 is a constant depending on the characteristics of the PV array and it has to be determined beforehand by determining the V_{MPP} and V_{OC} for different levels of irradiation and different temperatures. According to the constant k_1 has been reported to be between 0.71 and 0.78.

Once the constant of proportionality, k_1, is known, the MPP voltage V_{MPP} can be determined periodically by measuring V_{OC}. To measure V_{OC} the power converter has to be shut down momentarily so in each measurement a loss of power occurs. Another problem of this method is that it is incapable of tracking the MPP under irradiation slopes, because the determination of VMPP is not continuous. One more disadvantage is that the MPP reached is not the real one because the relationship is only an approximation.

To overcome these drawbacks, some solutions have been proposed, as is reported in.

For example, pilot cells can be used to obtain V_{OC}. They are solar cells that represent the PV array's cells and which are not used to produce electricity but to obtain characteristics parameters such as V_{OC} without interfering with the power converters. These pilot cells have to be carefully chosen and placed to represent the PV array characteristics and the irradiation conditions. One drawback of using these pilot cells is that the cost of the system is increased. Depending on the application, this technique can be used because it is very easy to implement and it is cheap - it does not require DSP or microcontroller control and just one voltage sensor is used [6].

6. Results and Simulation

The three foregoing methods are programmed under MATLAB environment. After running various programs the results are as follows:

6.1. Results of the Perturb and Observe Method:

The algorithm was showing in figure 4(b) is converted into program and after executing, we can find the results shown on figures 6(a, b, c). This method having a simple control structure and few parameters to measure. It operates by periodically disrupting the Panel voltage, and comparing the power previously issued with the new after disturbance, according to the organizational structure of the aroused method.

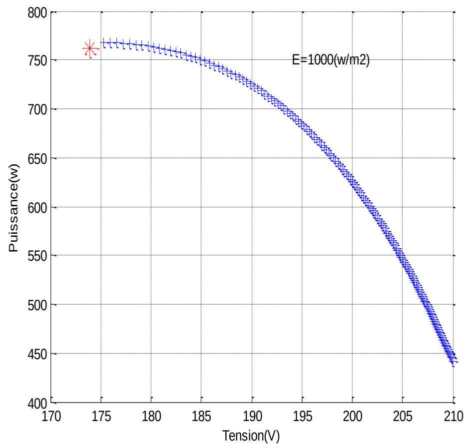

Fig. 6. (a). The Variation in Power Depending on the Voltage

The maximum power point to as coordinates (V= 174 V, P= 760 W) to provide illumination sets (1000 W/m2).

Of different test were operated the program for different levels of illumination, and every variation of illumination, point of maximum power is tracking as shown in the figure that follows

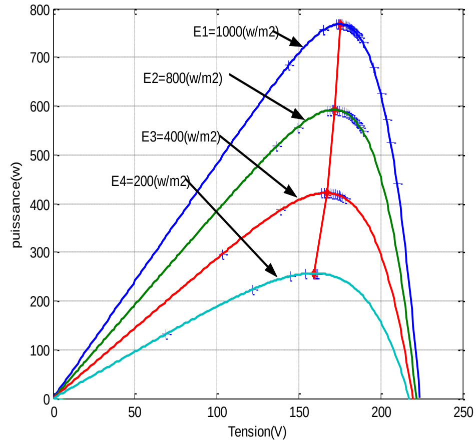

Fig. 6. (b). Tracking of the Power Point Maximum by (P & O) Algorithm to the Variable Illumination

The variation of the power function of the duty cycle of the chopper is shown in Figure 6(c), for a fixed illumination equal to 1000 W/m2

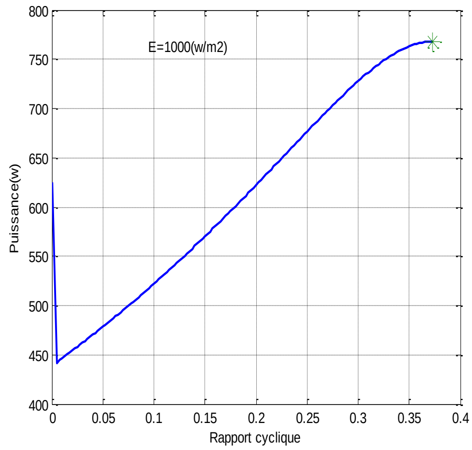

Fig. 6. (c). The Variation in Power Depending on the Cyclic Ratio

6.2. Results of the Incremental Conductance Method:

It has been said previously that this method uses seen by the source the conductance increment. The voltages and currents of the Panel are read by sensors, so that the controller can calculate conductance and incremental conductance, and decide on the direction of the increment, until their equality.

The algorithm in figure 5(b) is converted to program and after executing, we can find the results shown in figures 7(a, b, c).

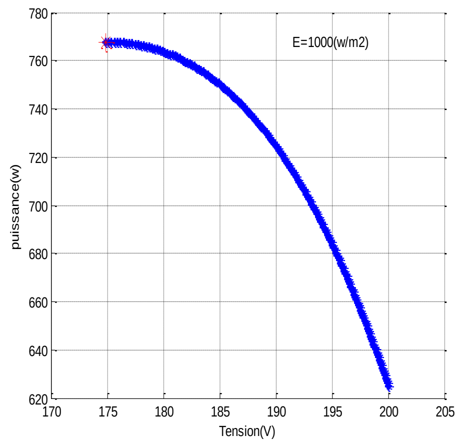

Fig. 7. (a) The Variation In Power Depending on The Voltage to The PPM

The maximum power point to as coordinate (V = 175 V, P = 765 W) to a fixed illumination equal to 1000 W/m2.

The different tests have been operated the program for different illumination levels, and every variation of illumination maximum power point is followed as shown in the figure that follows

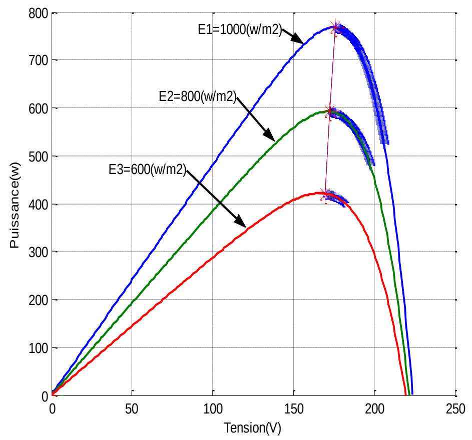

Fig. 7. (b). Tracking of the Power Point Maximum by (IC) Algorithm to the Variable Illumination

The difference between the power based on the cyclic ratio of the chopper is illustrated on figure 7(c) to a fixed illumination equal to 1000 W/m2. This variation is almost linear until the arrival to the maximum power point.

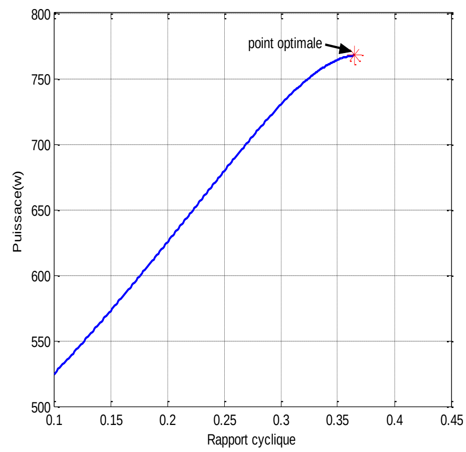

Fig. 7. (c) The Variation In Power Depending on The Cyclic Ratio

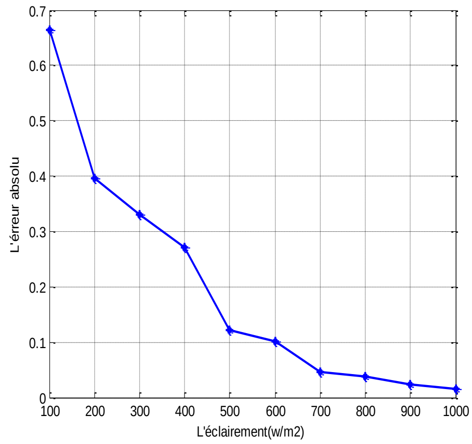

Fig. 8. The Variation In the Absolute Error Depending on The Illumination

Figure (8) clearly shows that the error deprived with the increase in the level of illumination

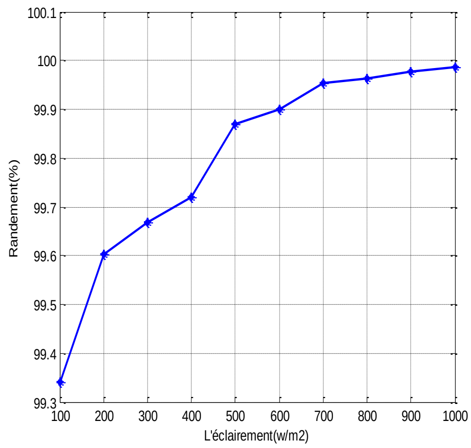

Fig. 9. The Variation of Performance Based on Illumination

This figure illustrates the variation in the performance of the incremental conductance method depending on the illumination, it is clear that the performance at a high level [99.3%, 99.99%]. It reaches its max for illuminance E = 1000 W/m^2.

6.3. Results of Fractional Open Circuit Voltage Method:

We said before that the maximum power point research is done from a reference derived from the open-circuit voltage, if the measured voltage is lower than the reference voltage, it increases the cyclic ratio α, where contrary we decrease this report, and the results of programming are shown in the following figures:

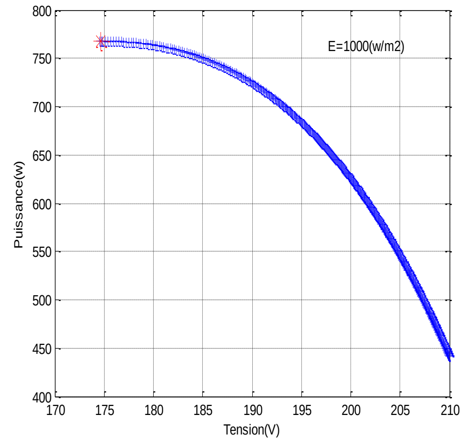

Fig. 10. (a). The Variation in Power Depending on the Voltage to the PPM

The maximum power point to as coordinate (V= 174.5 V, P= 765 W) for a fixed illumination equal à 1000 W/m2.

Of different test were operated the program for different illumination levels, and every variation of the maximum power point is followed as shown in the figure that follows

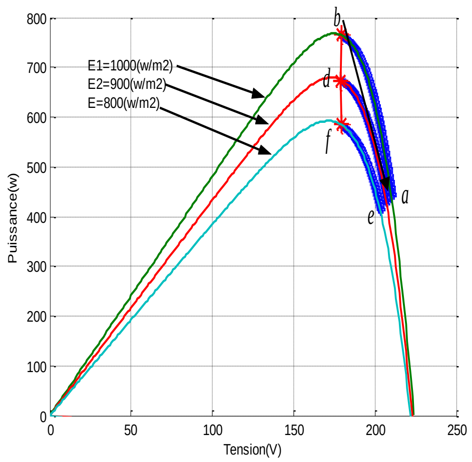

Fig. 10. (b) .Tracking of The Power Point Maximum by Fractional open circuit voltage method

By varying the light at a constant temperature (T = 25 °c), the points follow the path (b-c-d-e-f), from the illuminance E=1000w/m2) up to the illumination (E = 800 w/m2) figure 10 (b).

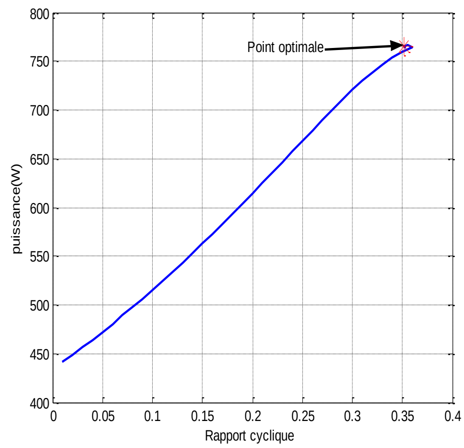

Fig. 10. (c). The Variation In Power Depending on The Cyclic Ratio

From figure 10 (c), there is a proportional relationship between the power and the duty cycle (α_{opt}=0.35).

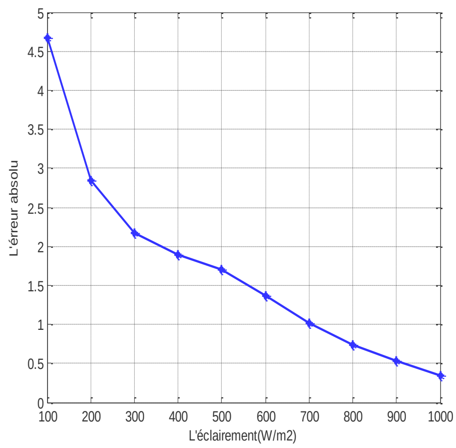

Fig. 11. The Variation in The Absolute Error Depending on The Illumination

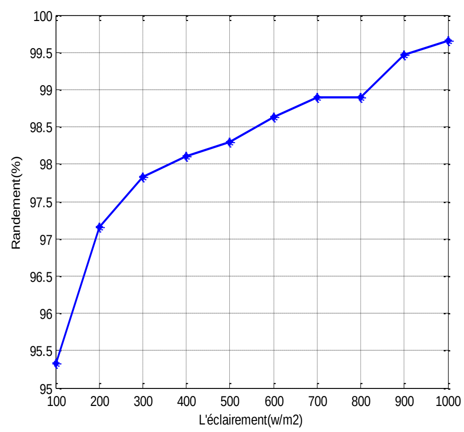

Fig. 12. The Variation of Performance Based on Illumination

Figure (11) shows the variation of the absolute error based on the illumination, it is minimum for large values of illumination, then it increases significantly towards the large values for small values of illumination as well as for performance figure (12) increases with the increase of the illumination of [95.3%, 99.6%]

6.4. Comparative Study of Three Algorithms:

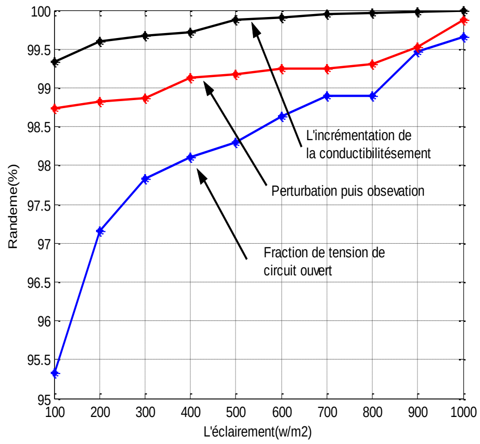

Fig.13. Comparison of Performances between The Three Methods

Table 1. Comparison of number of iteration and the average value of performance between the three algorithms

Technical's	Fractional open circuit voltage method	perturb and observe method	Incremental Conductance Method
Number of iteration	49	150	171
The average value of performance	98.2273	99.1930	99.7981

From the previous figure and table, incremental conductance method is the most effective compared to the other two methods.

For the perturb and observe method, it is effective for slow changes of illumination, but with power losses due to the oscillation around the PPM; These losses are likely to be even more important in the event of weather conditions that fluctuate quickly (like a cloudy day).

Such weather conditions pose a great problem for the research of the PPM whatever the algorithm used, indeed so that it can be effective, it is necessary that the static converter works in regime until new disturbances are carried out. Given the number of iterations required to achieve the PPM, the Fractional open circuit voltage technique is the fastest.

7. Conclusion

Comparative tests for the three MPPT algorithms (the Perturbation and Observation, Incremental Conductance and the Fractional open circuit voltage methods) using actual irradiance data in different weather conditions have been undertaken. The Incremental Conductance algorithm shows a better performance in terms of efficiency compared to the other algorithms under cloudy weather conditions. Even a small improvement of efficiency could bring substantial savings if the system is large. However, it could be difficult to justify the use of Incremental Conductance algorithm for small low-cost systems as the cost and availability are the two major aspect of system design and the Incremental Conductance algorithm will require four sensors more than the Perturbation and Observation algorithm and also it need more control loops.

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