Implementation MPPT approaches of PV system

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Abstract

Photovoltaic is one of the most important renewable energy sources. The output characteristics of a photovoltaic generator are influenced by climatic factors (insolation and temperature). So to extract maximum power, photovoltaic system uses different techniques that are called (MPPT). Various MPPT methods have been developed and proposed in literature. In this paper, we developed two approaches: P&O and short circuit methods. The attention here mainly is focused on experimental validation in real-time using a test bench composed by a resistive load powered by a photovoltaic generator (PVG) formed by ten photovoltaic panels via a boost chopper for the adaptation between the source and the load. The control part is provided by a computer incorporating a card DS1104 running environment Matlab/Simulink for visualization and data acquisition. This work is to see and compare experimentally the dynamics of the PV system under a random insolation scenario to improve the energy efficiency of the system. Also, a comparative study is made between these two types of methods. These results show clearly the effectiveness of our control with a very good performance.

Keywords: *Maximum power point tracking (MPPT), Photovoltaic generator (PVG), dSpace 1104, Perturb and observe (P&O)*

1. Introduction

We live a time of great concern in search of new solutions for electricity generation; cleaner and more durable solutions than the energy produced by power plants using oil, gas and uranium. These sources are polluting and run out increasingly. Gold the consumption of electrical energy is increasingly growing, this increase in consumption is accompanied by a huge increase in emissions of greenhouse gas; causing environmental problems in terms of global warming and climate change phenomenon. The most appropriate solution is the sustainable energy development which is to master the use, exploitation of resources accessible and renewable energy. Photovoltaic energy is the most promising energy source and most powerful among the renewable energies. Its principle translates in the direct conversion of solar radiation into electrical energy. This is done through a photovoltaic cell based on a phenomenon called photovoltaic effect, [1]. This cell is similar to a photodiode.

Recently, the attention has focused on the optimal operation of the PVG to obtain the most reliable and economic operation. However, photovoltaic systems suffer from high assignment of these characteristics by the climatic conditions change on the one hand. The maximum output is generated for an operating voltage and current on the other hand, [2]. Tracking the maximum power point of a PV array is a solution to provide maximum power to the load and ensure optimum operation for different climatic conditions. Various MPPT methods have been developed and proposed in literature. These MPPT methods are classified into two categories; indirect methods, [3, 4, 5] using databases of PV characteristics in different climate conditions, as the method of open circuit, the constant voltage method, short circuit method and direct methods, [6, 7] which use measurements of voltage and current of PV, the algorithm of these methods is essentially based on the actual variation of measurement as perturb and observe method, incremental conductance method.

This work focuses on the implementation in real-time of two approaches for extracting maximum power. It is structured in three parts. The first part rotates about the modeling of cells and influence of climatic conditions. The second part analyzes the operating principle of maximum power and gives the two proposed methods in this work. The third part presented the experimental results and discussion.

2. Photovoltaic energy

2.1. Modeling of solar cell

The solar cell is essentially a PN junction which directly converts light energy into electricity. It uses the properties of semi-conducting materials. The electrical model of a real photovoltaic cell used is a mono-diode model as shown in Fig.1.

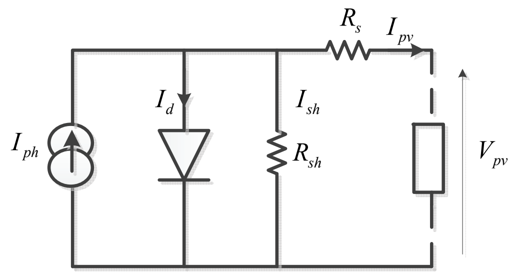

Figure 1. Equivalent circuit of a real solar cell

The equivalent circuit includes a current generator in parallel with a diode and two resistors: A series resistor (R_s) and parallel resistor "shunt" (R_{sh}).

- I_{ph} : Current photons,
- I_d : Diode current,
- I_s : Reverse saturation current of the diode,
- I_{pv} : Current supplied by the solar cell,
- I_{sh} : Current flowing through the resistor (R_{sh}),
- V_{pv} : Voltage across the cell.

When the cell is closed on a load, the operation is governed by the following equation:

$$I_{ph} = I_d + I_{pv} + I_{sh} \quad (1)$$

The output current from the cell is related to the voltage across a non-linear function:

$$f(V_{pv}, I_{pv}) = 0 \quad (2)$$

Another series-parallel configuration of several panels is called the photovoltaic generator (PVG), [8].

2.2. Case study

A photovoltaic panel TITAN-12-50 is available at ERCO research unit in Tunisia. It is on the roof with a temperature and insolation sensors. In our case, PVG is the association of 10 panels in series. To meet the characteristic $I_{pv} = f(V_{pv})$ of one panel, the load resistor value is varied from the open circuit to the short circuit value. Fig. 2 and Fig.3 represent respectively the current-voltage and power-voltage characteristics for a constant insolation and temperature ($E_s = 1000 W/m^2$, $T = 27°C$).

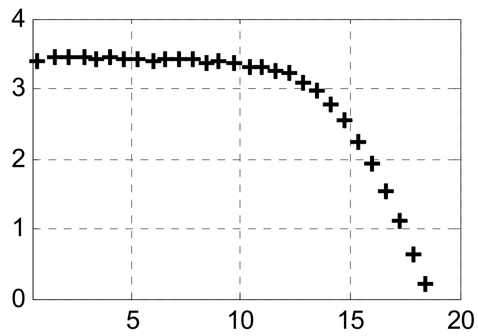

Figure 2. Current-voltage characteristic

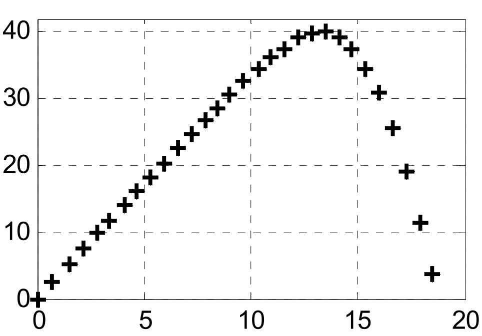

Figure 3. Power-voltage characteristic

The repeating of these try allows us to obtain a database that used to study the influence of climate parameters.

2.3. Influence of climatic parameters

A. Influence of insolation

The junction temperature value is fixed to show the influence of the insolation, [9].The curves in Fig.4 and Fig.5 show the evolution of real variables voltage, current and power for a constant temperature and an insolation worth 200, 300, 400, 600 and 900W / m².

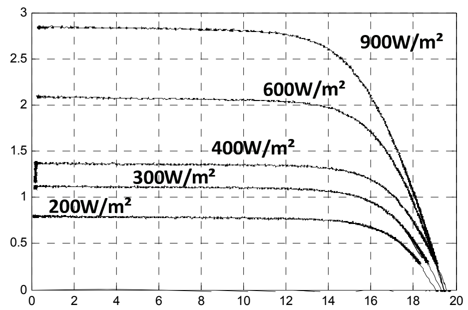

Figure 4. Current-voltage characteristic

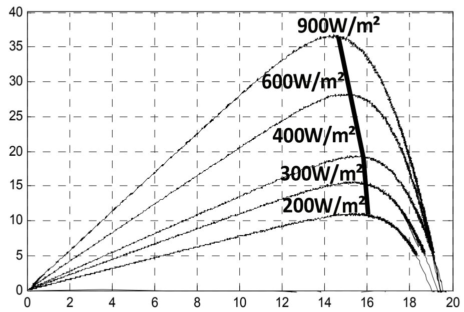

Figure 5. Power-voltage characteristic

We note that the short circuit current has the same behavior but the open circuit voltage V_{oc} decreases slightly with the decrease of insolation. The maximum power is also sensitive to insolation (E_s) as the short circuit current I_{cc} . Fig.6 shows the strong dependence between E_s and I_{cc} :

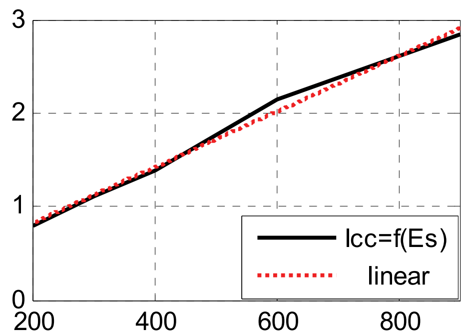

Figure 6. Evolution of the short circuit current versus insolation

The short circuit current varies linearly as a function of the insolation according to the following law variation:

$$I_{cc} = a_I E_s + b_I \quad (3)$$

With $a_I = 0.0029726$ and $b_I = 0.22962$

B. Influence of temperature

To show the influence of temperature, the insolation value is fixed at 600W/m². These curves in Fig.7 and Fig.8 correspond to a temperature of 23°C, 26°C, 28°C and 29 ° C.

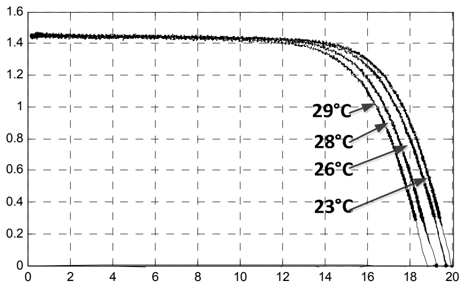

Figure 7. Current-voltage characteristic

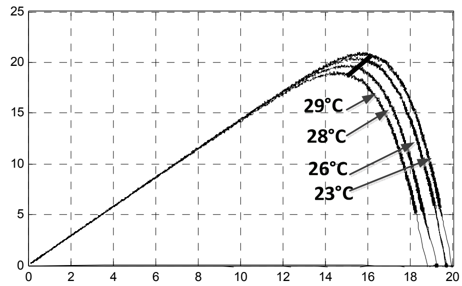

Figure 8. Power-voltage characteristic

The open circuit voltage is greatly influenced by the temperature change; it varies in the opposite sense, it's the same for the maximum power. Or the short circuit current is independent of temperature since only varies very little with temperature variation.

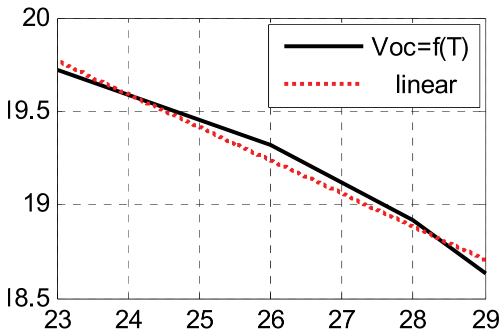

Figure 9. Evolution of the open circuit voltage versus temperature

So we can conclude that V_{oc} varies in the opposite direction of temperature (T) according to this law variation:

$$V_{oc} = a_V T + b_V \quad (4)$$

With $a_V = -0.19976$ and $b_V = 24.391$

3. PVG optimal operating

Simplicity, reliability and low cost allow direct connection to be the most used and answered, since the maximum power point of the PVG depends on the load impedance to which it is connected. But the major drawback of this direct connection is that the system operation point is often very far from the maximum power that can deliver the PVG. Or if the insolation is constant, power output will vary depending on the load. So inserting a MPPT controller's necessary for still provide maximum power to the load.

This MPPT as its name suggests can track the PVG maximum power point and allows controlling a static converter who plays the role of impedance adapter between the source and the load, [10]. This static converter is a parallel chopper because we need to increase the voltage. The following figure shows the schematic diagram of a photovoltaic system controlled by the MPPT:

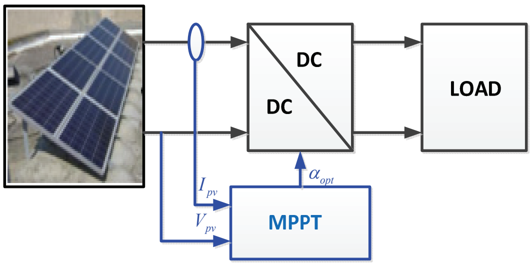

Figure 10. Block diagram of a photovoltaic system with MPPT

3.1. Boost chopper

For this chopper configuration, the average output voltage is greater than input hence its name booster. This structure requires a controlled switch (bipolar, MOS, IGBT ....) and a diode (Priming and blocking spontaneous). Fig.11 shows the block diagram of a boost chopper:

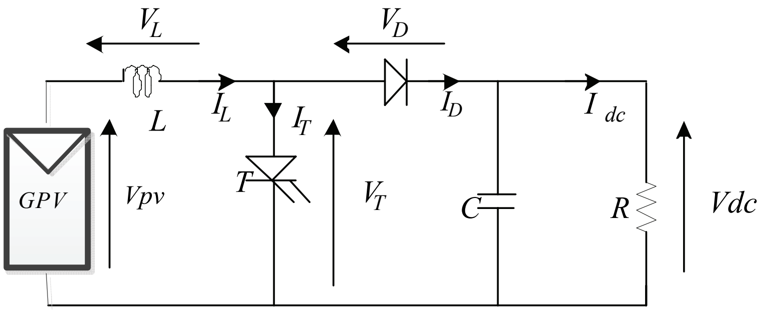

Figure 11. The block diagram of a boost chopper

The output voltage V_{dc} is expressed by equation (7) where a is the duty ratio.

$$V_{dc} = \frac{V_{pv}}{1 - a} \quad (5)$$

3.2. Proposed methods

The MPPT approaches are more or less complex; they are classified into two categories: direct and indirect approaches. Two approaches are presented in what follows. The direct one is the P&O method, the indirect approach is the short circuit method.

A. Direct approach

- P&O

The P&O technique is based on a periodic disturbance (increment or decrement) of the voltage or current PVG and comparing the output power P_{pv} with that of the previous cycle, [11]. Fig.12 gives the P&O technique principle.

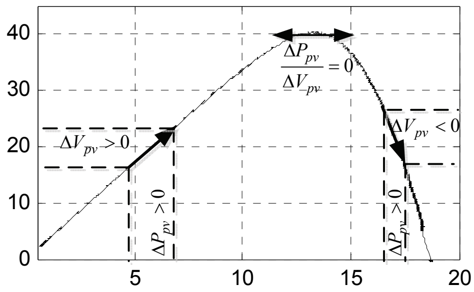

Figure 12. Principle of P&O method

If $(\frac{\P P_{pv}}{\P V_{pv}} > 0)$ therefore the control system moves the operating point in the same direction of the disturbance, but if $(\frac{\P P_{pv}}{\P V_{pv}} < 0)$ the control system moves the operating point in the opposite direction of the disturbance (indicated by the arrow).

B. Indirect methods

- The short circuit method

In this case we use the same characteristic that we used to show the influence of insolation. The optimal current varies linearly with the short circuit current, [12]. We can consider that:

$$I_{pv\_opt} = K_{cc} I_{cc} \tag{6}$$

With: $K_{cc} = 0.89$

4. Experimental results and discussion

4.1. Test bench

The general structure of the platform used is shown in Fig.13. For implementing the maximum power control approaches, we need to measure insolation, temperature, voltage and current. So we used some sensors that are acquired and performed in the research unit laboratory (ERCO). These sensors are key elements in the real-time control.

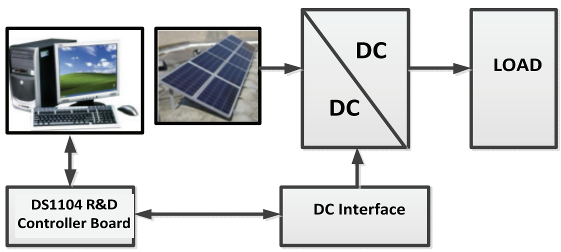

Figure 13. General structure of the test bench

The power portion is formed of a resistive load supplied by solar panels through a boost chopper. The control aspect is provided by a PC incorporating a map dSpace DS1104 running Matlab \ Simulink, [13]. The map DS1104 of dSpace is based on the Texas Instruments DSP TMS320F240. The switching period is $T_s = 50\,ms$, the chopper is fed by a DC voltage. All test results are recorded in real time. Fig.14 shows the photo of the test bench:

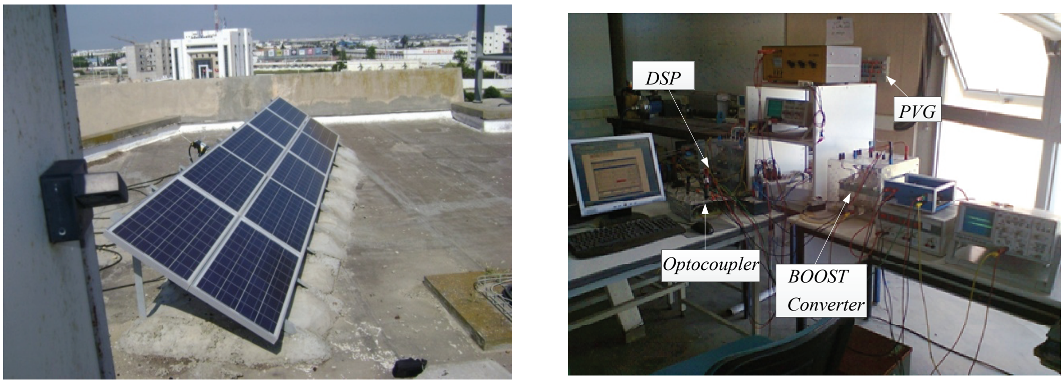

Figure 14. Photo of the test bench

Results are reported for one scenario: is the insolation real variation for a given load. In what follows, there is provided the results of two approaches developed and implemented on the processor dedicated.

We implemented on dSpace 1104 two approaches: P&O method and short circuit method.

4.2. Estimation of maximum power

The estimated optimal power is defined by the equation (7). This optimal power depends strongly on weather conditions. This is shown by the following equations:

$$P_{pv\_opt} = V_{pv\_opt} I_{pv\_opt} \quad (7)$$

From our database, we also find that the optimum voltage is almost equal to a fixed percentage of the open circuit voltage, [14], so:

$$P_{pv\_opt} = (K_{oc} V_{oc})(\mathrm{K_{cc} I_{cc}}) \quad (8)$$

With: $K_{oc} = 0.76$

The open circuit voltage depends strongly on the temperature while the short-circuit current depends on the illumination, so we obtain:

$$P_{pv\_opt} = (K_{oc}(a_V T + b_V))^{\prime}\ (\mathrm{K_{cc}}(a_I E_s + b_I)) \quad (9)$$

The efficiency is the ratio of power actually extracted by the PVG and the estimated maximum power.

$$h = \frac{P_{pv\_opt}}{P_{pv}} \quad (10)$$

This performance gives an idea about the effectiveness of our control.

4.3. Experimental results

A. Direct methods

- P&O

For a real scenario, the insolation varies between 870 and 910W / m², Fig.15. Fig.16 gives the evolution of the extracted power P_{pv} and the maximum power P_{pv_opt} . The ratio of the powers is called efficiency and represented by Fig.17. Finally, the displacement of the operating point for the proposed scenario is given in Fig.18.

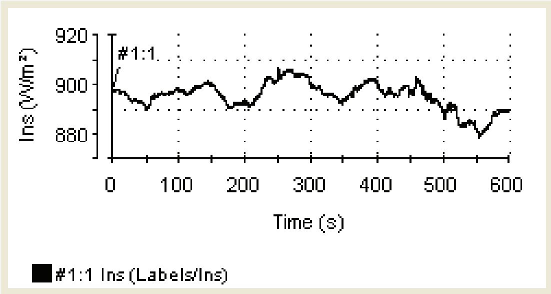

Figure 15. Real insolation

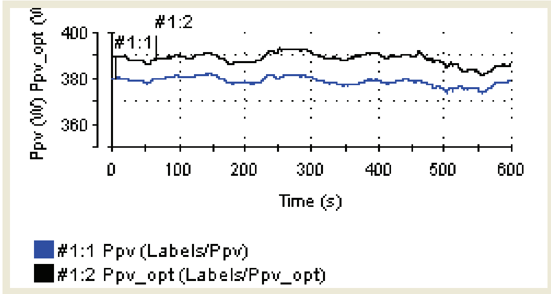

Figure 16. Extracted and maximum power

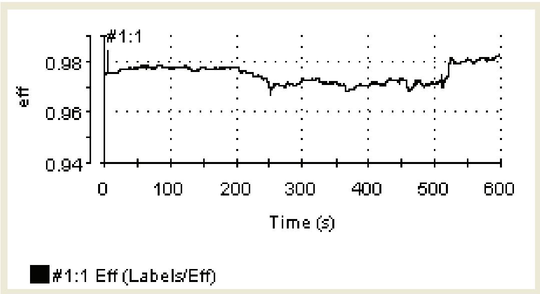

Figure 17. Efficiency

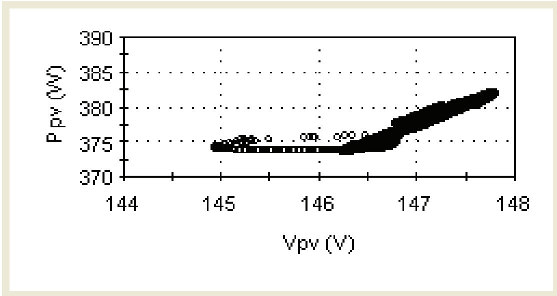

Figure 18. Evolution of the MPP

B. Indirect method

- The short circuit method

The general structure used for this method is shown in Fig.19.

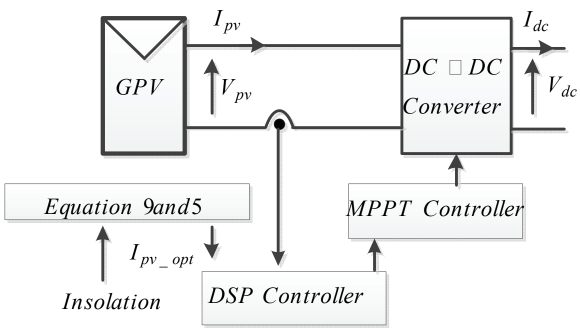

Figure 19. General structure

For a real scenario, the insolation varies between 500 and 900W / m², Fig.20. Fig.21 represents the evolution of the reference current and filtered current supplied by the generator PVG. The maximum efficiency is less than 95%, Fig.22. Finally we give the displacement of the operating point for the proposed scenario. Fig.23 shows that the voltage is varied between 145V and 150V.

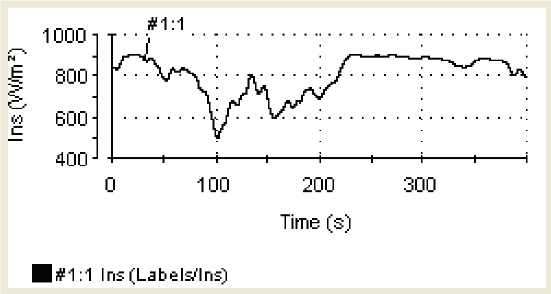

Figure 20. Changes in insolation

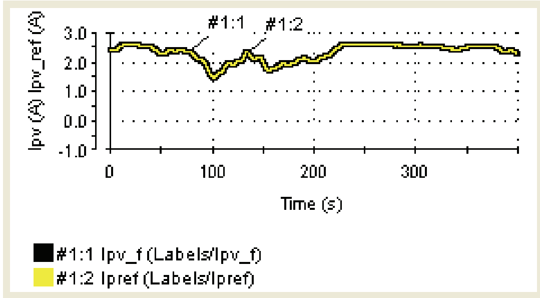

Figure 21. The evolution of data cycle

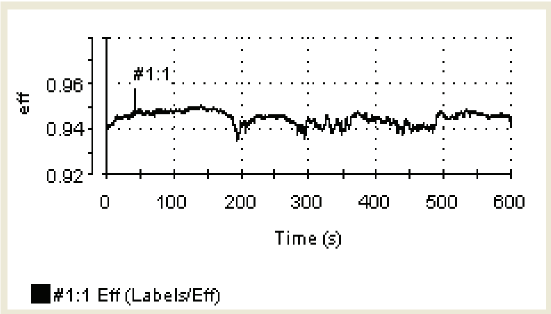

Figure 22. Efficiency

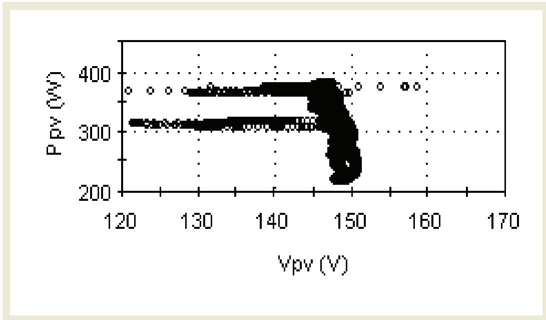

Figure 23. Evolution of the MPP

4.4. Discussion

We note for the first method (P&O) that the voltage generated by PVG varies around the voltage corresponding to operation at maximum power, confirming the validity of the approach implanted with a very good efficiency that can reach 98%.

We note for the second method (short circuit method), the both current overlap and move in the same direction as the insolation, thus confirming the MPPT operation. The efficiency in this case and with the scénario of insolation given by figure (20) does not exceed 95%.

The objective of the approaches studied is to generate maximum power to the load, or the difference is in the specificity of the methods. Indirect methods use databases of the characteristics of photovoltaic panels in different weather conditions as well as empirical mathematical equations to determine the maximum power point. These methods are often specific to each type of panel and therefore difficult to generalize. Although in many cases, they can be simple and inexpensive.

While direct methods are the methods that use dynamic measurements voltage and current of the panels and the algorithm is based on the change in these measurements. The advantage of these algorithms is that they do not require a database, [15].

5. Conclusion

The work shows an experimental validation in real-time using two approaches to control a maximum power of a PV system (P&O and short circuit methods). The first uses dynamic measurements voltage and current of the panels as it finds directly the maximum power point. For a random scenario of insolation, the efficiency can reach 98%. While, short circuit method is not sensitive to parametric variations. Here, the operating point is around the point at maximum power. The efficiency in this case does not exceed 95%.

The effectiveness of the system is verified and easily implemented due to the advancements of digital signal processors (DSP). The results validate the control MPPT which can significantly increase the efficiency of energy production from a PVG with a random scenario of insolation.

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