Improving the MPP of a PV System using Fuzzy Controller

Rania Benyoucef, Meriem Benbrahim and Samir Abdelhamid

***Abstract*—Maintaining the functioning of photovoltaic system at the maximum power point (MPP) requires the use of the maximum power point tracking (MPPT) control. Among the many MPPT algorithms suggested in the literature, we are interested in this study with the most commonly used techniques such as Increment of the conductance (Inc-Cond), Perturb and Observe (P&O) and Fuzzy logic (FL) algorithms. In the first step, a performance comparison between these three algorithms in PV system is achieved based simulation results obtained from MATLAB /SIMULINK environment. To mitigate the disadvantages of P&O and Inc-Cond classical techniques, we proposed on the second step a modified P&O and modified Inc-Cond methods, where a hybridization with the FL control is established. The results proved the superiority of the modified methods over conventional algorithms in terms of efficiency, accuracy and response speed.**

***Keywords*— MPPT control, Fuzzy Logic, modified P&O, modified Inc-Cond, PV system**

I. Introduction

The development that the world is witnessing leads to a continuous increase in daily energy consumption, this is what non-renewable energy sources can't guarantee over the years. This problem prompted researchers to develop another kind of energy sources that remain with the survival of the universe and have no negative effects on the environment such as photovoltaic energy. The principle of this energy is based on the transformation of the sun's rays to electricity by photovoltaic systems. These systems reach their maximum efficiency at a point named the maximum power point (MPP) that appears on PV panel curves; where the output power is maximum. However, the main downside of PV systems is that they are highly affected by temperature and solar irradiance [1]. To keep PV systems working at the MPP despite weather changes, maximum power point tracking (MPPT) techniques are used to control a DC-DC converter in order to extract optimal power output from PV system.

There are several studies dealing with this topic. The authors in [2] deduced that the use of the MPPT control improves the efficiency of photovoltaic installations considerably. The results obtained proved that for a very short period the system regulated by an MPPT control converges towards the optimal conditions regardless of weather conditions and load variation. A comparison between different aspects of the most famous MPPT techniques Perturb & Observe (P&O), Incremental Conductance (Inc-Cond), measurements of open circuit voltage (FCO) or of short-circuit current (FCC) and fuzzy logic control (FLC) was reviewed and studied using MATLAB Simulink environment in [3], this work concluded the fuzzy controller shows better performance compared to other methods. In [4], a PV system based on a three-phase interleaved Boost converter is studied. To operate system at maximum power, two MPPT cases are implemented P&O and Inc-Cond. The output of this study showed that the MPP detection time for both algorithms is nearly equal. However, Inc-Cond exposed better performance than P&O concerning vibrations around the MPP. In [1], a new hybrid MPPT method is proposed which named AIC-IT2-TSK FLC. This method is characterized by the good determination of initial variable and MPPT operation in steady conditions. This is what made it better than the classical MPPT methods in terms of speed tracking, stability and robustness which are clearly indicated by the experimental results. Authors in [5] improved a fuzzy controller adapted to a classical P&O algorithm for a synchronous motor connected to PV panels. Based on the obtained results, the proposed method showed a significant effectiveness compared to the conventional P&O in several aspects as speed tracking, accuracy and stability. In [6–7], the benefits and the restrictions of the P&O method have been introduced. In practical, it is the most used method for its easy and inexpensive implementation despite the quality of its MPP tracking performance. Even so, this feature is lost when irradiation and temperature change rapidly. In addition, this leads to the appearance of ripples around the MPP and misusing some of the available energy. Thus, to avoid that the authors suggested a new strategy of the P&O method to boost its Performance. Reference [8] compared conventional control strategies (P&O and Inc-Cond) with fuzzy controller. The different tests results confirmed advantage of FLC over P&O and Inc-Cond. Regardless of varying conditions, the FLC was flexible and expressed better performance, including faster response times and less fluctuation. More details about FLC efficiency and performance under different environmental conditions are elucidated in [9]. Reference [10] addressed a performance evaluation of four MPPTs which are Inc-Cond,

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Hill-Climbing, P&O and Fuzzy algorithms for a PV system. The results of the study noted that the Hill-Climbing and P&O have the greater amplitude of the oscillations around MPP than the other methods. FLC has the best efficiency. However, the optimal algorithm in this study was Inc-Cond, because it was the fastest to reach the MPP.

This paper discusses the performance evaluation of three MPPT algorithms named Inc-Cond, P&O and Fuzzy logic algorithms and a proposed hybrid methods (FL based P&O and FL based Inc-Cond) to ameliorate MPP tracking performance. According to the response time, ripples around the MPP, efficiency and accuracy the evaluation is done. This paper is organized as follows: Section 2 is dedicated to the description of the PV system. Section 3 explains the approach used and details each MPPT algorithm. Section 4 presenting and interpreting the simulation results in MATLAB/Simulink. Finally, this paper is completed by a conclusion.

II. DESCRIPTION OF PHOTOVOLTAIC SYSTEM

Fig.1 shows the PV power circuit components. It consists of different blocks which are a PV panel (energy source), DC-DC boost converter and a Load. The DC-DC boost converter is used to regulate the PV panel output voltage to a bigger value; so that the panel delivers maximum energy [3]-[9]-[10].

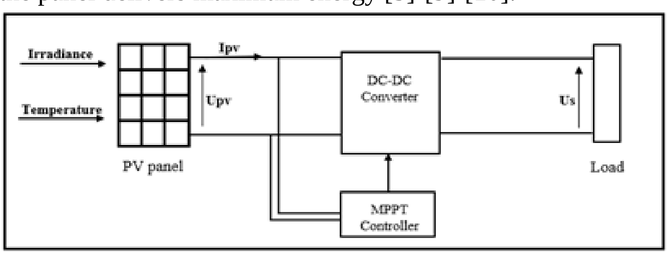


Fig.1: PV power circuit components

A. *Photovoltaic panel*

In this study, we used a solar panel injected from the Simulink library, type 1Soltech 1STH-215-P, which has the following parameters presented in TABLE I.

TABLE I: PV PANEL CHARACTERISTICS AT 25°C AND 1000W/M2

Parameters	Values
Parallel strings Np	40
Series connected per string Ns	10
Cells per module Ncell	60
Voltage at maximum power Vmp (V)	290
Current at maximum power Imp (A)	293.15
Maximum power Pmax (W)	85000

The electrical properties of the PV panel are directly affected by changes in irradiance (G) and temperature (T) [8]. Fig. 2 represents the impact of the irradiance changes (800 w /m2 to 1000 w/m2) on the PV curves while temperature is constant (25°C). We can see that there is a proportionality between irradiance level and the maximum power. The current value increases with the increase in the level of irradiance and the voltage is almost unchanged (290V).

Changing temperature between 10°C and 45°C (irradiance equal to 1000w/m2), kept the current value constant while voltage varies remarkably as Fig.3 illustrates.

Through the PV curves, we observe that the power curve is characterized by a point where the output power is extreme, named MPP. However, the drawback of this point is its strongly dependence on weather variations. To keep system working according to this point despite environmental conditions, we need to use the maximum power point tracking algorithms (MPPT) [4]. Its regulation concept is based on the auto-variation of the duty cycle to the suitable value. Then, this value will be delivered to converter so as to optimise the extracted power [2]-[10].

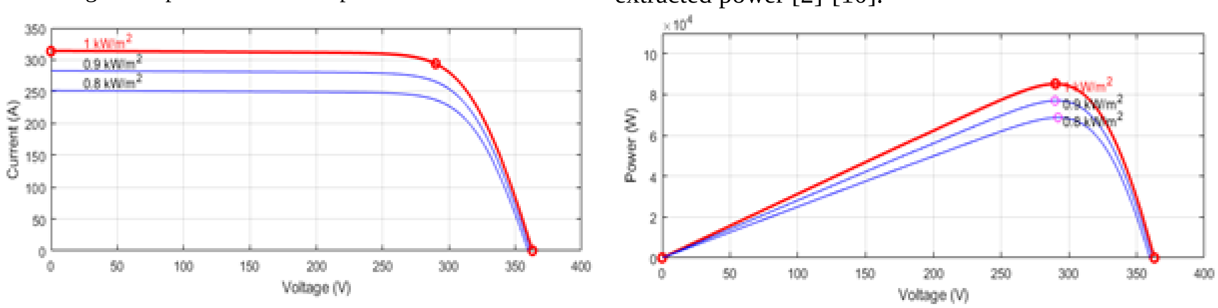


Fig. 2: (a) I–V curve (b) P–V curve for constant T and different G

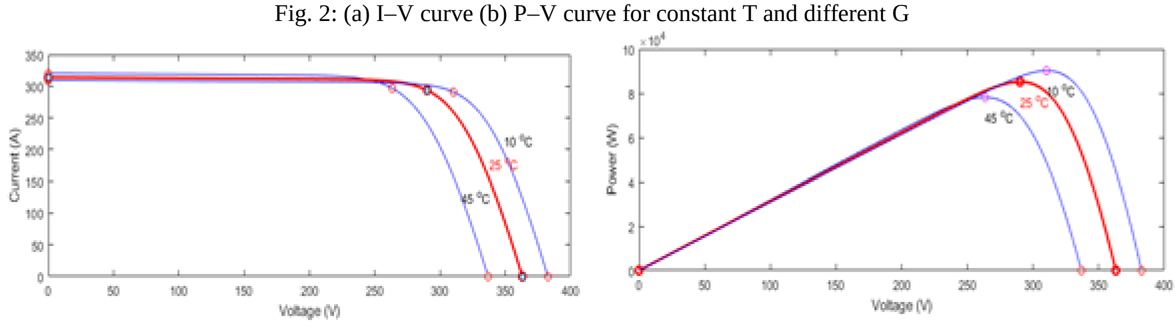


Fig. 3: (a) I–V curve (b) P–V curve for constant G and different T

B. DC-DC boost converter

The adaptation between PV panel and the load is allowed by the interleaved boost converter (IBC), in order to extract optimal output energy from PV system while the role of the interleaving technique is to decrease current ripples [3]-[4]. Fig.4 illustrates the structure of the boost converter which contains three identical phases. Switches S1, S2 and S3 are IGBTs with antiparallel diodes and the operating values of the IBC are noted in TABLE II.

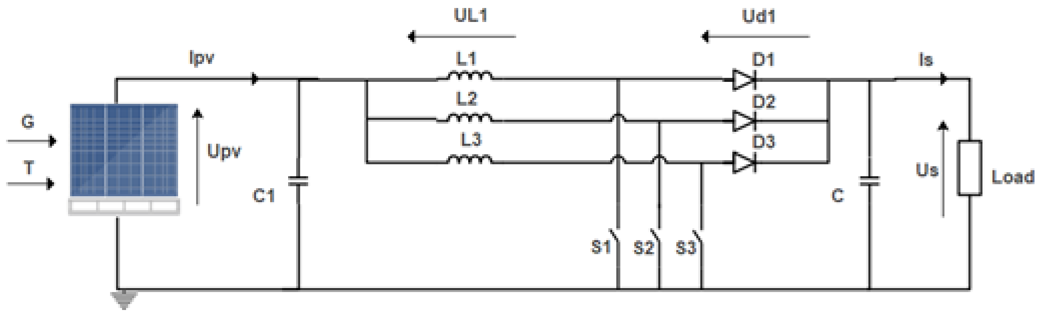


Fig. 4: Three-phase interleaved boost converter

TABLE II: THE ARRANGEMENT OF CHANNELS

Parameters	Values
L_1=L_2=L_3 (H)	0.002
C_1 (F)	0.0033
C (F)	0.00047
f (Hz)	20000

The model of the IBC is detailed in [4] and is offered as:

$$\dot{U}_{PV} = \frac{I_{PV}}{C_1} - \frac{1}{C_1}[M]^T[I_L] \quad (1)$$

$$[\dot{I}_L] = \frac{U_{PV} - U_S}{L}[M] + \frac{U_S}{L}[\alpha] \quad (2)$$

$$[I_L] = \begin{bmatrix} I_{L1} \\ I_{L2} \\ I_{L3} \end{bmatrix} \quad [\alpha] = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \end{bmatrix} \quad [M] = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} \quad (3)$$

Where U_s and U_{pv} are respectively the output and input voltage, I_{L1} to I_{L3} present the inductor currents, with α1 to α3 the control inputs duty cycles.

III. PROPOSED APPROACH

In this study, we focused on the commonly used MPPT algorithms called Inc-Cond, P&O and FL algorithms which are reviewed in this part. The rest of this section presented the principles of the proposed hybrid methods Fuzzy based P&O and Fuzzy based Inc-Cond.

A. Perturb and observe algorithm

The principle of this method is originally summarized in its name. In which a perturbation on the PV panel voltage is performed while searching on the optimal duty cycle. Thus, the PV power delivered is calculated at t = k and it is compared to its old value calculated at t = k • 1. Then we observed the result.

If the power increases, the MPP is approached and the duty cycle variation is kept in the same direction. In the other hand, if the power decreases, we move away from the MPP. Then, the direction of the duty cycle variation must be inversed. P&O is the most useful method for its easy implementation and good performance. But it does not work well when weather conditions change rapidly [3]-[5]-[9].

B. Incremental conductance algorithm

To find out the position of the working point relative to the MPP, this technique depends on the continuous comparison of two values, the value of the conductance (I/V) and the value of its increment (dI/dV) till getting the MPP. Duty cycle is demoted if (-I/V) is lower than (dI/dV). Otherwise, the duty cycle is risen if (-I/V) is higher than (dI/dV). Inc-Cond is more difficult to execute compared with P&O despite the resembling of their performances [3]-[5]-[8].

C. Fuzzy logic algorithm

In contrast to conventional MPPT techniques, the fuzzy logic control is characterized with its good performance at rapid weather changes and of the elimination of ripples around MPP. So, it is able to upgrade tracking performance. The fuzzy controller consists of three stages: Fuzzification, inference and defuzzification.

The step of Fuzzification permits transformation of numerical input variables into fuzzy sets. In this study, the reference voltage change is the output while the power change and the voltage change are the inputs defined by:

$$\Delta V_{PV}(K) = \left(V_{PV}(K) - V_{PV}(K-1)\right) \quad (4)$$

$$\Delta I_{PV}(K) = \left(I_{PV}(K) - I_{PV}(K-1)\right) \quad (5)$$

$$\Delta P_{PV}(K) = \Delta V_{PV}(K) \times \Delta I_{PV}(K) \quad (6)$$

Different used variables membership functions are revealed with a triangular function and they are designated to five (5) linguistic variables named like NB (Negative Big), NS (Negative Small), ZE (Zero Approximately), PS (Positive Small) and PB (Positive Big) as showed in Fig.4.

In the inference step, fuzzy rules base is built from 25 (If then) laws, in which it includes all instructions about supervised parameters, as expressed in TABLE III.

Lastly, in the step of defuzzification, the centroid type is used to transform output fuzzy subdivisions into numerical values [3]-[5]-[8]-[9].

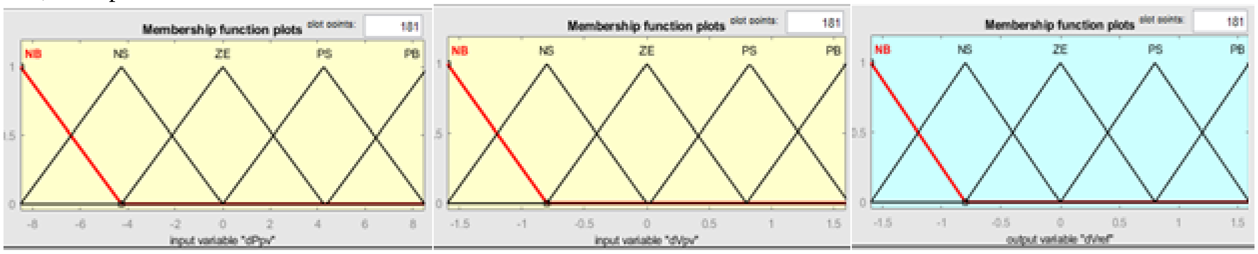


Fig. 5: Membership functions of the inputs (a) power change (b) voltage change and the output (c) reference voltage change.

TABLE III. THE INFERENCE RULES

ΔV_{ref}	ΔV_{PV}					
ΔP_{PV}		**NB**	**NS**	**ZE**	**PS**	**PB**
	NB	PS	PB	NB	NB	NS
	NS	PS	PS	NS	NS	NS
	ZE	ZE	ZE	ZE	ZE	ZE
	PS	NS	NS	PS	PS	PS
	PB	NS	NB	PB	PB	PS

D. Fuzzy based P&O and Fuzzy based Inc-Cond

To cancel classical P&O and Inc-Cond techniques limitations, we suggested to make a hybridization between these techniques and fuzzy logic controller. The role of FLC is to create optimal voltage reference. Then, this reference voltage will be sent to P&O or Inc-Cond block to carry on its MPP tracking process, whereas IBC is used to preserve constant output voltage. The suggested modified P&O and Inc-Cond algorithms diagrams are illustrated in Figure 6. Applying these proposed modified methods ensures a high accuracy level, a high dynamic response speed and less fluctuations around MPP that leads to avoid waste a lot of energy [5]-[9].

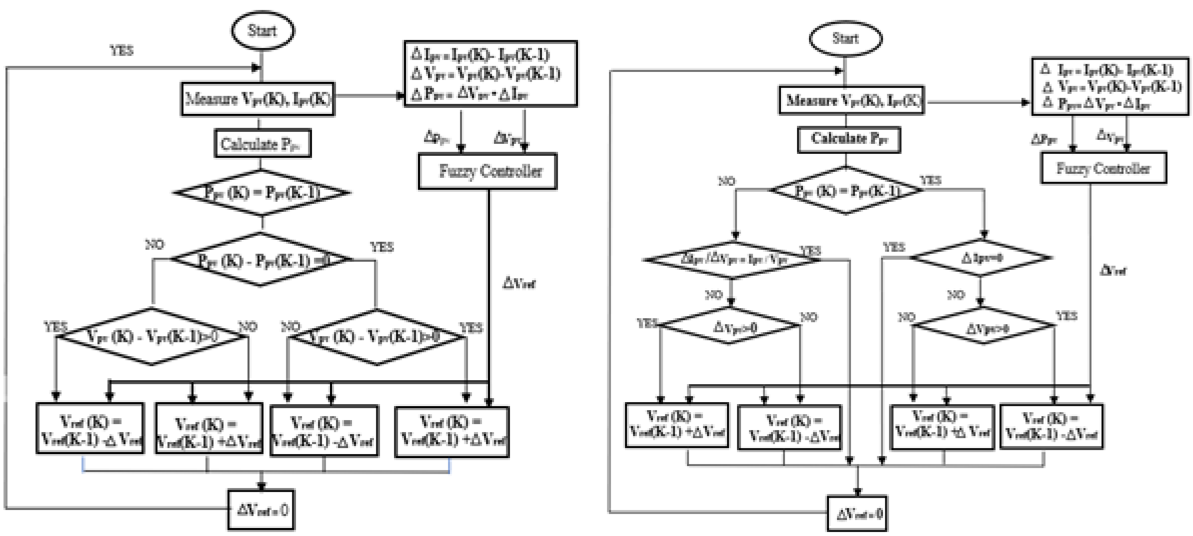


Fig. 6: Hybrid algorithms (a) Fuzzy based P&O (b) Fuzzy based Inc-Cond.

IV. RESULTS AND DISCUSSIONS.

The studied PV system and the reviewed maximum power point tracking algorithms are simulated under a constant level of temperature (25 C°) and a variation of irradiance (800 to 1000 w/m2) as presented in Fig.7. This section presents simulation results of two steps and their interpretations according to time response, oscillations around MPP, efficiency and accuracy.

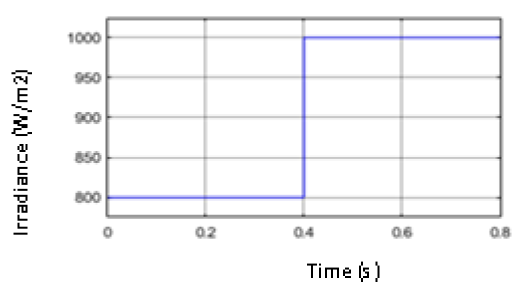


Fig.7: Change of irradiance

A. Performance comparison between Inc-Cond, FL and P&O algorithms

In the first step, a comparison between Inc-Cond, FL and P&O techniques is achieved. Fig.8 presents the PV voltage of the three MPPT algorithms. We notice that FL respond faster than other algorithms where MPP detection time in the case of FL is equal to 0.002s, while in the case of Inc and P&O the detection times are respectively 0.003s and 0.015s. Fig.9 shows the PV power of the three MPPT algorithms over 0.8s, in the transient mode and at the instance when irradiance varies (0.4s). P&O presents the most important oscillations nearly the optimal point which leads to lose a significant part of energy. Conversely with FL that performs very good in the different parts of simulation interval without undulations cons to classical algorithms which are hardly influenced by variation.

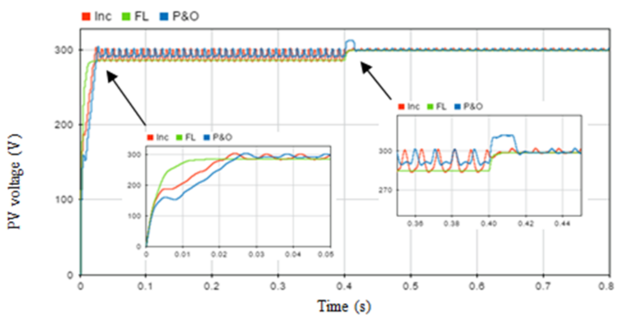


Fig.8: Photovoltaic voltage of MPPT techniques

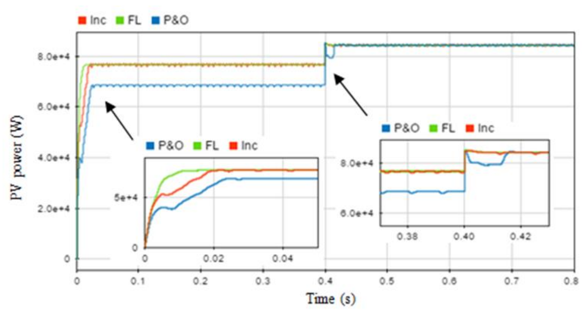
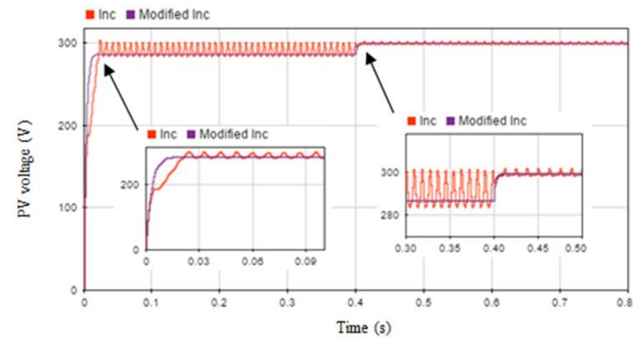


Fig.9: Photovoltaic Power of MPPT techniques

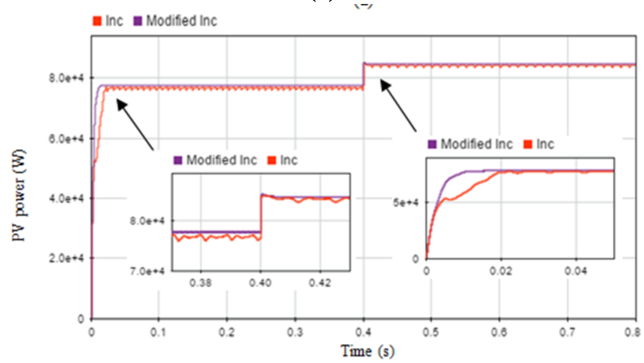
B. Modified Inc-Cond and Modified P&O against classical Inc-Cond and classical P&O respectively

In the second step, a comparative study was conducted on classical MPPT algorithms and classical MPPTs based on FL in order to present the performance of both methods under the same climatic conditions. The temperature remained constant (25C°) and at t= 0.4s irradiance level varied from 800 to 1000 W/m2 as seen before in Fig.7. Fig.10 (a) and (b) show respectively the results obtained from comparison between conventional and modified Inc-Cond in terms of voltage variations and Pv power over 0.8s, in transient mode and at the moment when irradiance change. It is clearly deduced that the convergence of fuzzy logic control based Inc-Cond to steady state is faster than the convergence of classical Inc-Cond. Additionally, in the case of modified Inc-Cond fluctuations has been completely removed around MPP and in steady state compare to classical Inc-Cond where fluctuations were important. This resulted in a power gain of 440 W greater than the power extracted when using traditional Inc-Cond.

Fig.11(a), (b) illustrate respectively P&O and modified P&O comparison results in terms of PV voltage, PV power evolution. The results of the modified P&O were better than those of conventional method. The response of the modified P&O was faster. After variation in irradiance, the extracted power has reached its maximum in 0.0019s while it has taken 0.015s in the case of P&O. Ripples are eliminated and the power is 550W more than P&O extracted power. So, it is concluded that efficiency and accuracy of modified methods are higher than those of the classical methods as illustrated in TABLE IV.

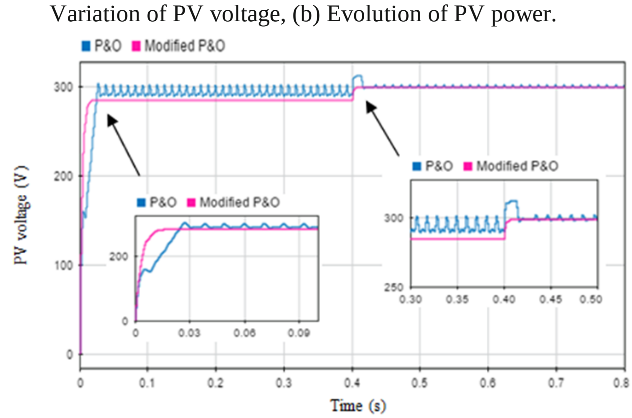


(a)

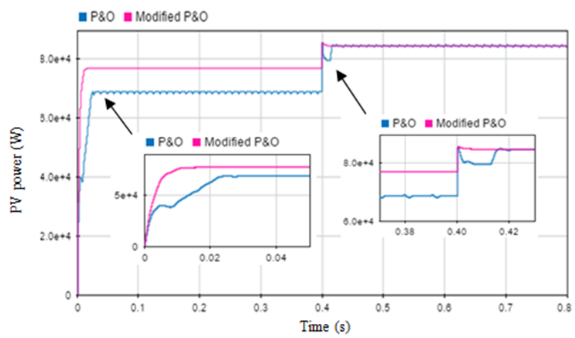


(b)

Fig.10. Inc-Cond and modified Inc-Cond comparison results: (a) Variation of PV voltage, (b) Evolution of PV power.



(a)



(b)

Fig.11: P&O and modified P&O comparison results: (a) PV voltage, (b) PV power

TABLE IV: COMPARISON OF MPPT METHODS

MPPTs	P&O	Modified P&O	Inc-Cond	Modified Inc-Cond
MPP (W)	8.386e4	8.441e4	8.442e4	8.466e4
Speed	+	+++++	+++	+++++
Ripples	-	----------	-	----------
Accuracy %	95	96.53	96.43	96.57
Efficiency %	98.65	99.3	99.31	99.60

V. CONCLUSION

The aim of this paper is to improve the tracking of the maximum power point in the selected photovoltaic system. The study included two steps. The first one was a comparison between FL, classical Inc-Cond and classical P&O algorithms. The results proved that the performance of Inc-Cond was better than P&O, but despite the tracking performance and response speed that distinguished Inc-Cond it had a lot of undesired vibrations in the entire simulation field. The FL Controller had the most engaging results in this step with no undulations and a very fast response. In the second step, fuzzy based Inc-Cond and fuzzy based P&O are applied in order to cancel the limitations of traditional methods and this was proven by simulation results. That led to an increase in the MPP value and thus the levels of efficiency and accuracy.

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