An Improved MPPT Incremental Conductance Algorithm Using T-S Fuzzy System for Photovoltaic Panel

Hanen Abbes[*‡], Hafedh Abid[**], Kais Loukil[*]

[*]Department of Electrical Engineering, National Engineering School of Sfax, Laboratory of Computer and embedded Systems (Lab-CES), University of Sfax, PB 173, 3038, Sfax, Tunisia

[**]Department of Electrical Engineering, National Engineering School of Sfax, Laboratory of Sciences and techniques of Automatic control & computer engineering (Lab-STA)

[‡]Corresponding Author; Hanen Abbes, National Engineering School of Sfax, PB 173, 3038, Tel: + 216 74 274 08, Fax: +216 74 275 595, hanenabbes2009@yahoo.fr

Abstract-Maximum Power Point Tracking (MPPT) is an essential technique that tracks the maximum power point of photovoltaic panel. Since, conventional MPPT algorithm uses a fixed step to get the optimal value of the duty cycle, many drawbacks occur. Thus, the purpose of this presented work is to suggest an improved MPPT technique which enhances the choice of the variable step size of the duty cycle and therefore improves the performances of photovoltaic system. Indeed, the concept of this new algorithm is to compute the variable step according to the slope value of Power-Voltage characteristic for photovoltaic panel. Then, it provides the appropriate value of duty cycle. In this paper, the concept and the features of the conventional Incremental conductance algorithm are examined. Then, the improved MPPT algorithm which relies on fuzzy logic technique is explained. Simulation results are provided to exhibit the efficiency of the proposed MPPT approach.

Keywords — Photovoltaic, MPPT, technique controller, Fuzzy Logic, Incremental Conductance.

1. Introduction

In recent years, energy crisis and environmental issues such as pollution and global warming have been progressively increasing the research attention to renewable energy sources. Photovoltaic energy, as a kind of free, clean and inexhaustible energy seems to be the most promising widespread utilization. However, the major challenge of photovoltaic system applications is the variation of power generation with atmospheric conditions. So, it is crucial to increase the efficiency of the photovoltaic (PV) system which should operate at the maximum power point.

Therefore, a great effort has been made in the development of maximum power point tracking (MPPT) techniques while considering the variation of parameters such as temperature, solar irradiation or the load of the system. In the literature, several algorithms have been developed to track

maximum power point. These algorithms vary in popularity, simplicity, reliability, accuracy, required time for tracking, cost and others.

The most well known of MPPT algorithms are: Hill-Climbing, Perturb & Observe (P&O) and Incremental Conductance (INC) [1][2]. Other simple algorithms are developed such as the short circuit current and open circuit voltage [3][4]. There are also intelligent algorithms namely fuzzy logic technique [5][6]. Among all these algorithms, the P&O and INC are widely used thanks to their simple implementation. The Perturb and Observe method perturbs the PV array voltage then observes its impact on PV power and therefore decides to increase or decrease reference voltage to track the maximum power point (MPP). The INC method is based on the slope value computation of the Power-Voltage characteristic. This value is equal to zero at the MPP, negative on the right side and positive on the left side. Since, these

algorithms use fixed step to reach optimal power, some drawbacks are taken place: slowly converging to maximum power point and oscillations around this point. Several techniques have been proposed in the literature to remove drawbacks of these classical algorithms [10]. X. Huang and L.Ren [7] developed a technique which adjusts the step size of power converter; if the operating point is in the right side of the P-V characteristic, the variable step is equal to a simple step. If the operating point is in the left, the variable step is equal to four times the step in the right side. This method reduces oscillations around the MPP. However, when the MPP is reached; the variation must be the same for the two sides of P-V characteristic. P. Wang and Z. Zhou [8] suggested an improved algorithm that optimizes the selection of the step size. In fact, this method relies on a multistage variable step so it uses multiple parameters. It enhances the quickness of the maximum power point tracking and reduces oscillations. The drawback of this method is the choice of these parameters that requires high accuracy and hard computation. Therefore, fuzzy logic controller (FLC) has been introduced to provide new performances. The concept of fuzzy logic is used in many techniques as demonstrated in [1][12]. It has been applied because it handles the non linearity of the system and it does not require an accurate mathematical model. The main aim of this paper is to investigate the concept of conventional INC algorithm and FLC technique to produce an improved MPPT controller. Indeed, the conventional INC is studied and evaluated. Then, the new MPPT controller using fuzzy logic concept takes advantages of the INC algorithm and reduces the eventual drawbacks. The make use of Matlab/SIMULINK tool highlights the performances of the improved MPPT algorithm. So, this paper is organized as follows: in section 2, the photovoltaic panel is described. In section 3; we recall the operation of the conventional INC algorithm. In section 4, the new FLC technique approach is explained. In section 5; simulation results are exhibited and then some discussions are made. Finally, we have a conclusion.

2. Photovoltaic Panel

Photovoltaic system includes: photovoltaic panel, power converter and MPPT controller. Photovoltaic cell, which is the basic component of the photovoltaic panel, can be considered as a current source (I_{ph}). An accurate mathematical model is necessary to draw the electrical characteristic of photovoltaic panel. The equivalent circuit of photovoltaic cell, as shown in Fig.1, is modelled by a photocurrent source, parallel diode, shunt resistance (R_{sh}) and series resistance (R_s). Therefore, the I_{PV} current provided by photovoltaic cell is given by equation (1). Where I_d and I_R are respectively the current which flows through the diode and the shunt resistance. T is the temperature and G is the irradiation.
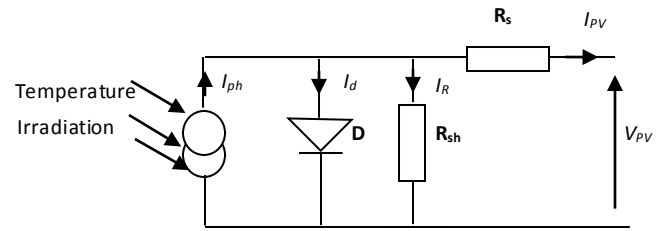

Fig. 1.Equivalent circuit of photovoltaic cell

$$I_{PV} = I_{ph} - I_d - I_R \quad (1)$$

$$I_{ph} = (I_{cc} + K_I(T_k - T_{ref}))\frac{G}{G_{ref}} \quad (2)$$

$$I_d = I_s \left[\exp\left(\frac{V_{PV} + R_s I_{PV}}{nV_T}\right) - 1 \right] \quad (3)$$

$$I_R = \frac{V_{PV} + R_s I_{PV}}{R_{sh}} \quad (4)$$

Where:

T_{ref} : reference temperature (25°C)
G_{ref}: reference irradiation (1000W/m^2)
I_{cc} : Short-Circuit current
I_s: saturation current of the junction in the cell,
n: quality factor of the diode which is between 1 and 2,
K_I : short-circuit current/temperature coefficient
V_T : Thermodynamic potential

Figure 2 shows a nonlinear characteristic of the photovoltaic cell. This characteristic varies with the change in metrological terms. As the optimal power point varies broadly according to weather conditions, a power converter switch should be controlled by a specific algorithm to track the maximum power point. In next sections, we recall the operation of the conventional MPPT algorithm and then we enhance its operation using fuzzy logic technique to get perfect performances.
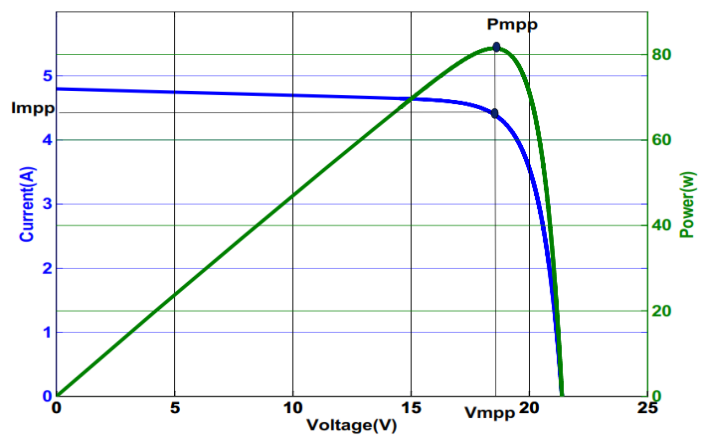

Fig. 2. I-V and P-V characteristics of photovoltaic cell

3. Conventional Inc with Direct Control Method

As we mentioned previously, this technique computes the slope value of P-V characteristic (dP/dV) as given by equation (5).

$$\frac{dP}{dV} = \frac{d(VI)}{dV} = I + \frac{dI}{dV}V \quad (5)$$

At the MPP : $\frac{dP}{dV} = 0$, so :

$$\frac{I}{V} = -\frac{dI}{dV} \quad (6)$$

Figure 3 recalls the flowchart of INC algorithm. The position of the operating point compared to the maximum power point is known whenever conductance (I/V) and incremental conductance (dI/dV) are known. Consequently, the MPP can be tracked by comparing the instantaneous conductance (I/V) to the incremental conductance (dI/dV). If instantaneous conductance is greater than the opposite of incremental conductance, we decrease duty cycle (d). If instantaneous conductance is less than the opposite of incremental conductance, we increase duty cycle [9].
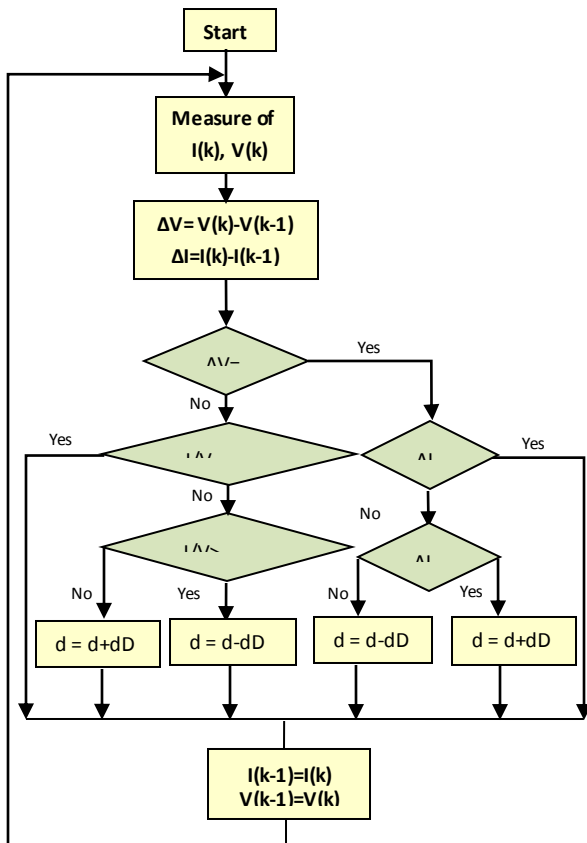

Fig. 3. Flowchart of the INC direct control algorithm

This process is repeated until maximum power point is reached. This conventional algorithm is applied for tracking maximum power point. It is a popular algorithm characterized with its simplicity and its easy implementation. However, it has some drawbacks:

➤ It is slowly converging to the optimal power point.

➤ At steady-state, PV output power presents oscillations around the maximum power point.

➤ Under a rapid irradiation change, the operating point moves away from optimal point.

Figure 4 shows the behaviour and the eventual drawbacks of the INC algorithm.
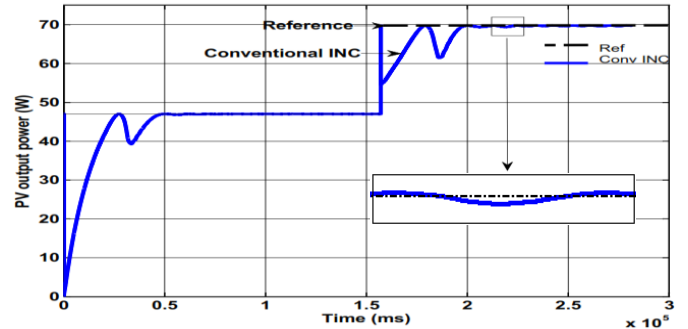
(a)
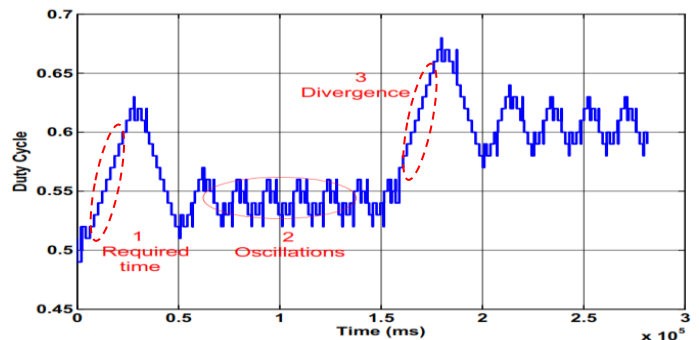
(b)

Fig. 4. Drawbacks of the INC algorithm: (a) PV output power and (b) duty cycle

4. Modified INC based on FLC Technique

The diagram of photovoltaic system with the new MPPT controller is given by Fig.5. The fuzzy logic concept is harnessed for non linear systems especially for maximum power point tracking system to greatly improve dynamic and steady state performances [13]. Thus, in this section, we suggest a modified incremental conductance based on fuzzy logic technique. In fact, the proposed MPPT controller is conceived to draw on the benefits of INC algorithm and get rid of the most reported drawbacks.

The proposed MPPT controller includes two main modules: the purpose of the first module is to generate a variable step size Δd while the second module uses this latest

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step to compute the entire value of duty cycle (D). In fact, the first block relies on fuzzy logic Takagi-Sugeno (T-S) model.
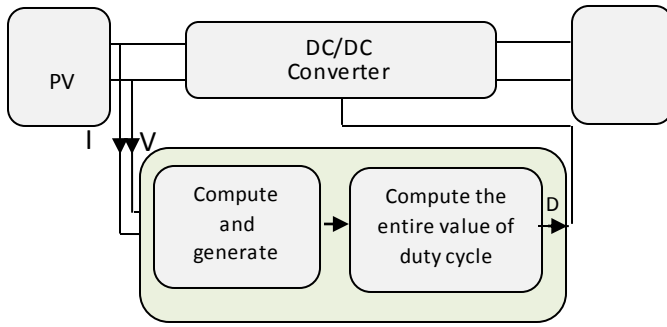
Fig. 5. Block diagram of the PV system with the proposed controller

The fuzzy logic type operates in two stages: fuzzification process and inference engine. Indeed, during fuzzification phase numerical input variables are converted into linguistic variables. Then, a rule table is made while considering Sugeno inference method. Finally, a concrete output value is provided. Given equation (6), the two inputs of FLC system E1 and E2 are made as shown equations (7) and (8):

$$E1 = \frac{I}{V} + \frac{dI}{dV} \quad (7)$$

And,

$$E2 = E1(k) - E1(k-1) \quad (8)$$

The output control signal is a variable step: Δd. Figure 6 shows the P-V characteristic divided into three regions. In fact, the output variable Δd is computed thanks to the slope value of the P-V characteristic (E1) and the variation of the slope value (E2). The slope value can be negative ② (on the right side), positive ③ (on the left side) and roughly zero ① (near the MPP).
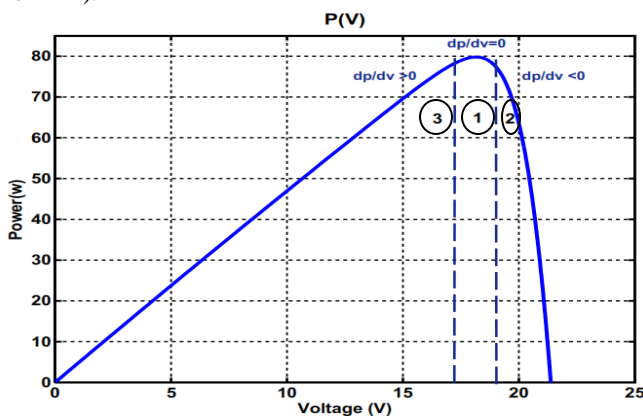
Fig. 6. Sign of the slope value on the P-V characteristic

Figure 7 illustrates the boundaries of the slope value which are set using two extreme characteristics (from T=5°C and G=100W/m2 to T=75°C and G=20W/m2). In fact, since, the P-V characteristic varies with temperature and irradiation,

the slope value varies. For these reasons, we considered these changes to make the ranges of the slope value. In addition, the slope values are classified into five sets: Zero (Z), Positive Small (PS), Negative Small (NS), Positive Big (PB) and Negative Big value (NB).
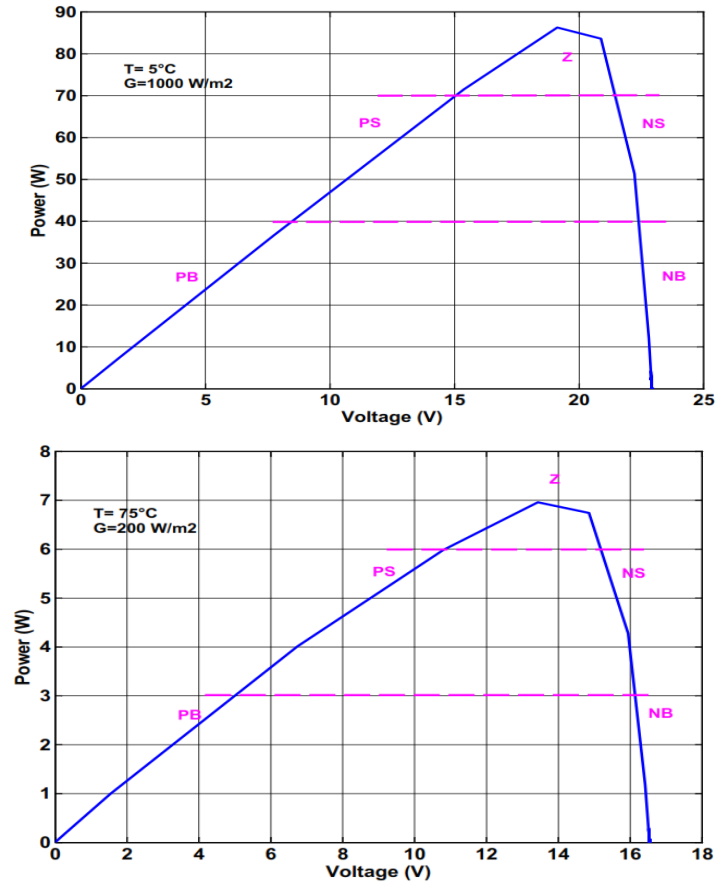
Fig. 7. Distribution of P-V characteristic according to the slope value for the pair of (temperature, irradiation) : (5°C,1000W/m2) and (75°C, 200W/m2)

The membership functions of inputs variables, which are given by Fig.8, are asymmetric and denser at the centre. This kind of membership functions provides more sensitivity and guarantees flexibility. Consequently, for each region, we attributed a step value size. For region (Z) we assigned a small step size which is equal to α/6, for the small regions (NS and PS) we assigned a medium step size which is equal to 2α/3 and for the big regions (NB and PB) we assigned a big step size which is equal to α. Table 1 summarizes the FLC system having twenty five rules whose output is a concrete variable. These rules are elaborated using the concept of incremental conductance algorithm. To better understand, we explain an example of a control rule: If (E1 is NB) and (E2 is NB) then (step is α); It means that ; if the slope has a huge value (region 3) and the change of the slope is also big, therefore the operating point is far from the MPP and we should set a big step value.
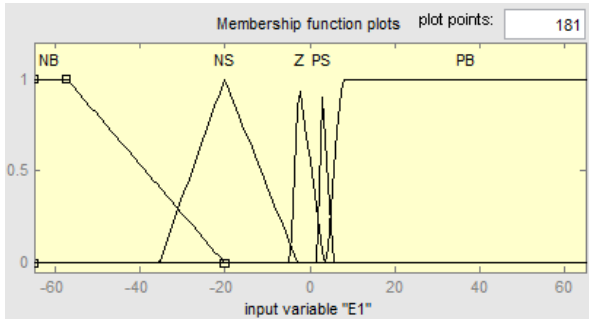
(a)
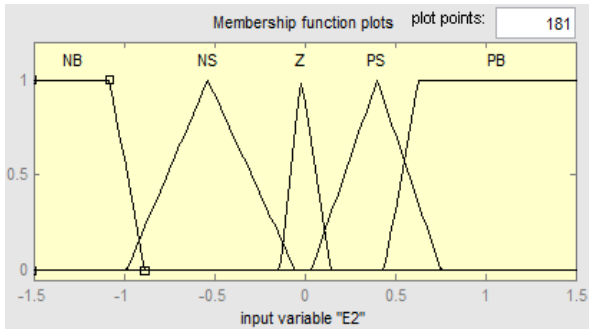
(b)

Fig.8. Membership functions for (a) input E1 (b) input E2

Table 1. Inference rule table

E2 \ E1	NB	NS	Z	PS	PB
NB	α	$2\alpha/3$	$2\alpha/3$	$2\alpha/3$	α
NS	$2\alpha/3$	$2\alpha/3$	$2\alpha/3$	$2\alpha/3$	α
Z	α	$\alpha/6$	$2\alpha/3$	$\alpha/6$	$\alpha/6$
PS	$2\alpha/3$	$2\alpha/3$	$2\alpha/3$	$2\alpha/3$	$2\alpha/3$
PB	$\alpha/6$	$2\alpha/3$	$2\alpha/3$	$2\alpha/3$	α

Therefore, the fuzzy control algorithm is implemented using Takagi-Sugeno inference system. As a result of this first algorithm part, an adequate step size Δd is computed. In second stage, this step is sent to a second block. This block determines the direction for tracking the MPP and then decrease or increase the duty cycle. Indeed, if the slope value is positive, we are in the left side so we should decrease the duty cycle. Else, we are in the right side so we should increase the duty cycle in order to track the MPP.

5. Results and Discussions

Figure 9 shows PV system with the proposed MPPT controller designed on Matlab/Simulink. This system model is

composed of three main blocks: photovoltaic model which represents the source of energy, static DC-DC converter which its type depends on the role that we want to achieve through the PV system and the MPPT controller. You found many types of the DC-DC converter such as Buck, Boost or Buck-Boost… In this work, we focus on a Boost type. The output current and voltage are fed as inputs to the both FLC block (to determine the appropriate step) and to the second block to have finally a signal control.
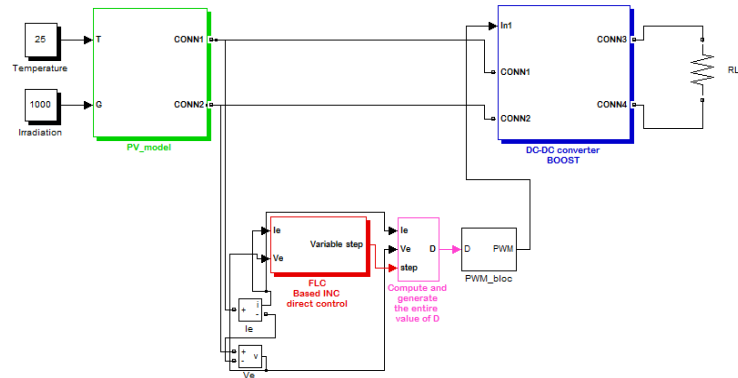

Fig. 9. Complete Simulink model of MPPT algorithm using FLC

The computed value of D is supplied to generate pulses for switching device of DC- DC converter.

Figure 10 gives simulation results for the proposed MPPT technique. Figures 11 and 12 illustrate the variations of temperature and irradiation and show the impact of these changes on the behaviour of the new MPPT controller. Therefore, we will show the performances of the improved algorithm.
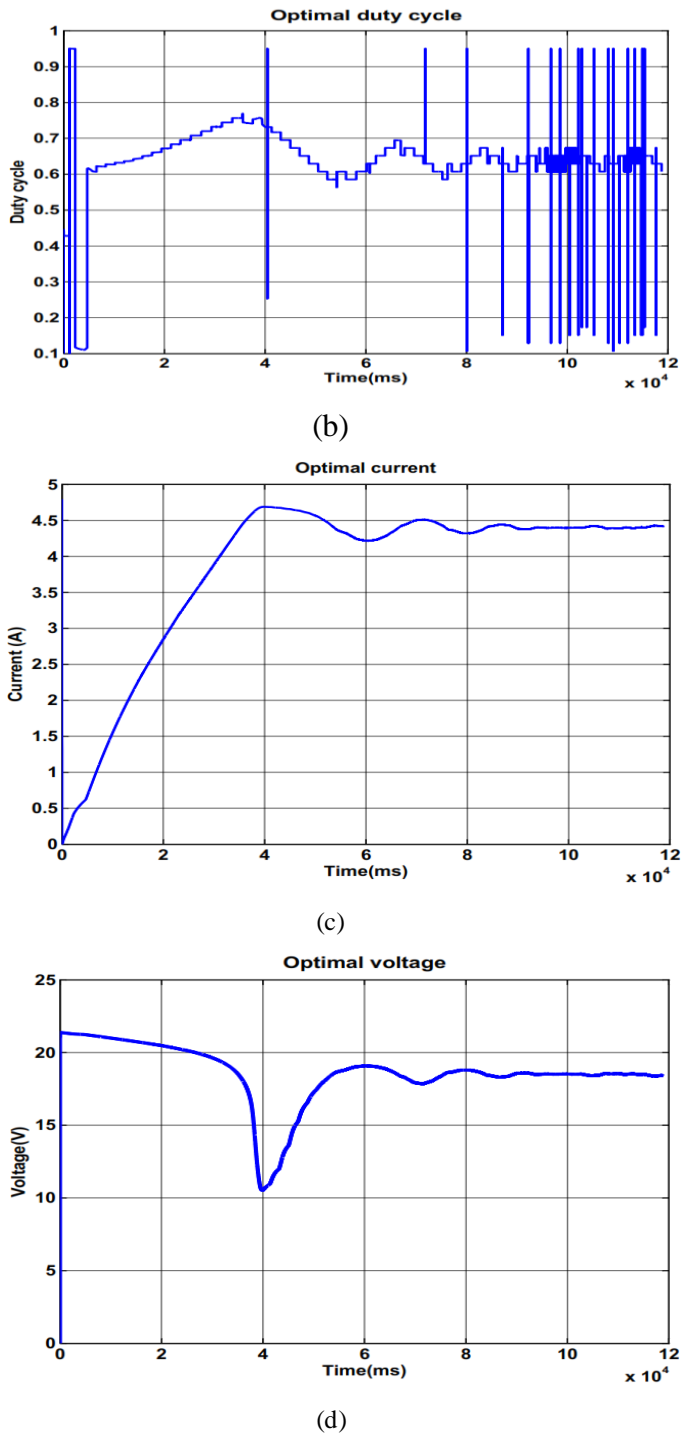

(a)

(b)

(c)

(d)
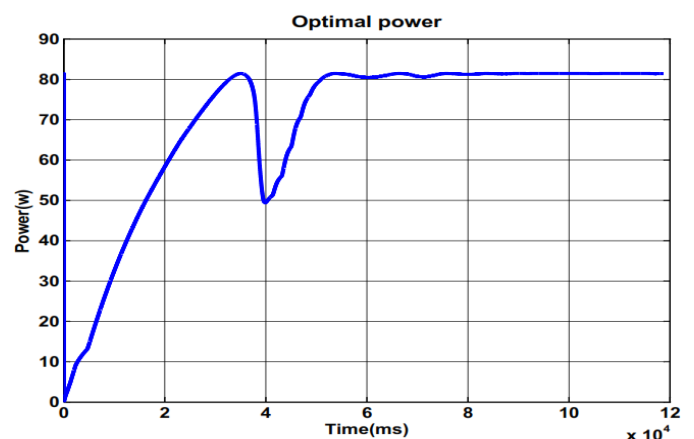
Fig. 10. Optimal values of PV system based on proposed MPPT (a): Power, (b): Duty cycle, (c) : Current and (d): Voltage

Figure 13 illustrates simulation results of the improved MPPT compared to the conventional INC algorithm. These results prove that tracking speed is increased compared to conventional algorithm and the PV output power presents less oscillation around the maximum power point. Moreover, the proposed MPPT controller seems to operate better under a rapid irradiation change. In fact, the fuzzy rules operate by providing the appropriate variable step according to slope value. Therefore, the new MPPT algorithm has perfect

performances: the optimum power point is reached within a short time and oscillations around the optimum value are very smaller than the conventional algorithm. Consequently, we overcame the three major drawbacks of INC algorithm thanks to the fuzzy logic technique.
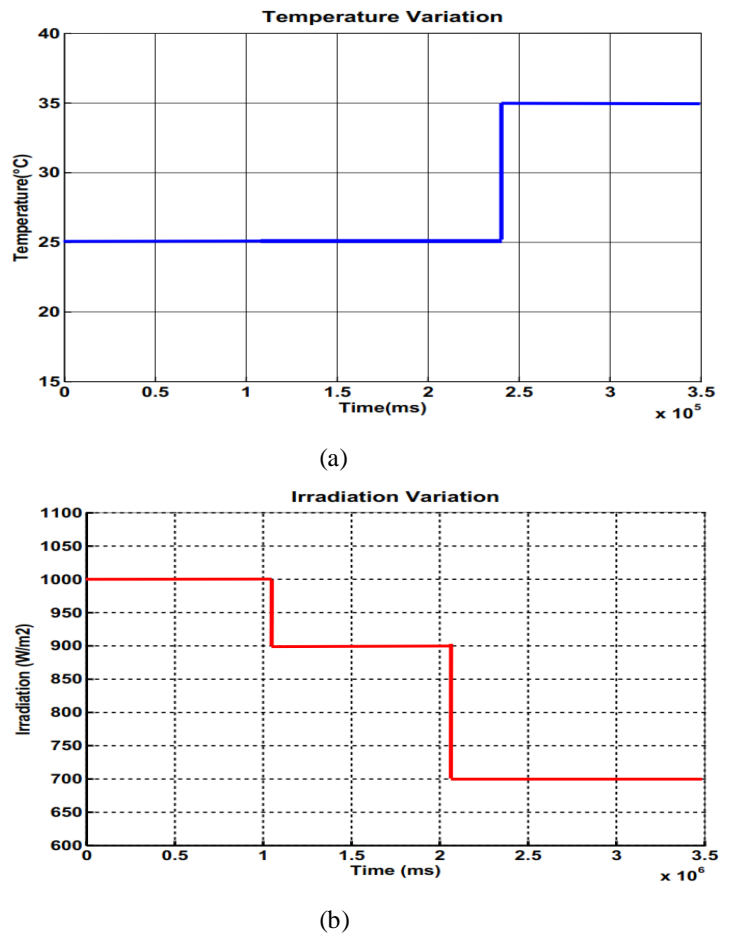

(a)

(b)

Fig. 11. Variations of temperature (a) and irradiation (b)
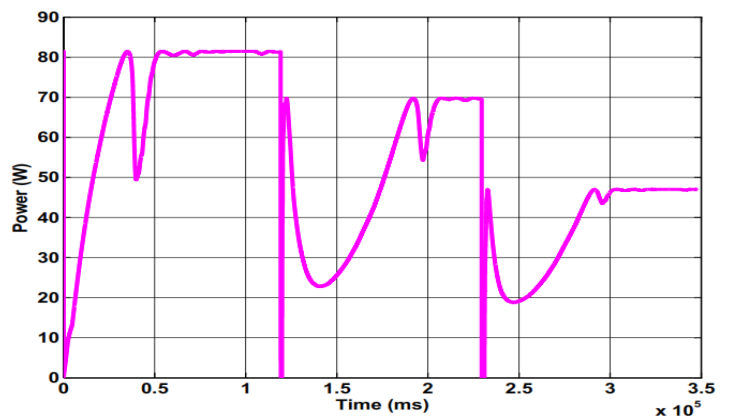

Fig. 12. PV output power for proposed improved INC under temperature and irradiation variations
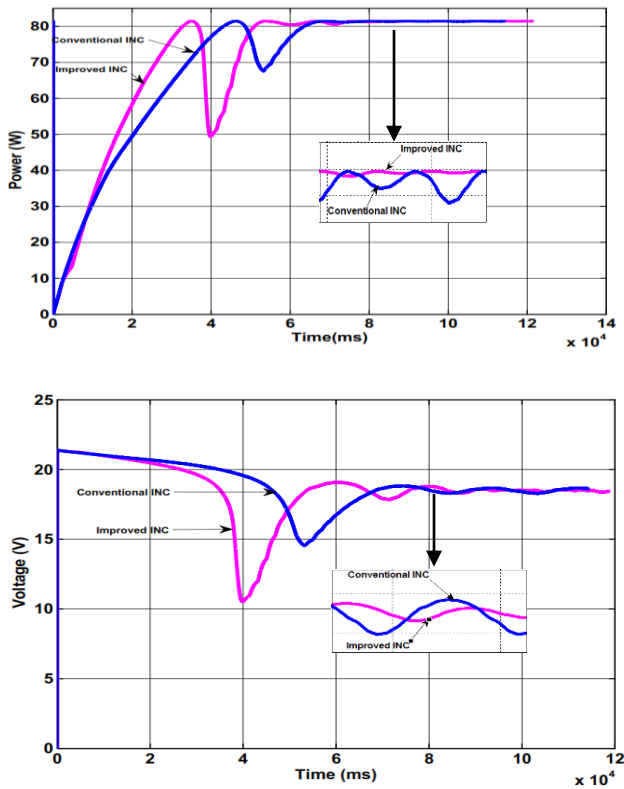
Fig. 13. PV output power and voltage for conventional INC compared to the improved INC algorithm

6. Characteristics of PV Array Panel

The characteristics of the used PV array panel are summarized in table 2:

Table 2. Characteristics of PV array panel

Np	Ns	K_I	V_{oc}	I_{cc}	Pmax
1	36	0.00171A/°C	21.38V	4.8A	81.5 W

Vmax	Rs	Rp	R_L
18.4V	0.09 Ω	100 Ω	30 Ω

7. Conclusion

In this paper, the MPPT incremental conductance method is improved using T-S fuzzy logic concept. Indeed, by investigating the structure and the regulation of conventional INC technique, a new approach is designed while fuzzifying the rules of incremental conductance direct control to provide an adequate variable step. Therefore, we reduced the drawbacks of conventional algorithm and we acquired new performances. Simulation results showed an ideal functioning of the modified approach compared to the conventional INC approach. Thus, we get an efficient MPPT technique that reaches MPP with less oscillation and good behaviour during varying weather conditions.

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