Proposed Algorithm MPPT for Photovoltaic System

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Abstract – *A proposed algorithm MPPT (Maximum Power Point Tracking) is proposed in this paper. When the insolation change rapidly, the P&O (Perturb and Observe) algorithm is used to adjust the operating point of the PV (Photovoltaic) array close to the MPP (Maximum Power Point) for fast tracking; also, the INC (Incremental Conductance) algorithm and the fuzzy controller skip drawbacks of the P&O algorithm by decreasing oscillations around the MPP and the underestimated. In addition, to improve the control precision, the effectiveness of proposed algorithm is validated by simulation using Matlab/Simulink, the simulation results show that the proposed algorithm tracks the MPP quickly, reduces the oscillation around the MPP effectively and improves the energy conversion efficiency of the PV panel.*

I. Introduction

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Solar energy is one of the most important sources of renewable energy, so that research has been increasingly important in recent years, it's one of the most promising alternatives for traditional sources of energy for this reason has been used increasingly to produce electricity. Many researchers focus on the control methods using a variety of algorithms called MPPT to extract the maximum power in different weather conditions, especially when the sudden change, taking into account its impact on the overall system.

In solar energy field, many researchers have worked to develop MPPT algorithms. [1] Has presented simulation and hardware to implement the INC algorithm applied to buck chopper by Compared the different MPPT methods, also apply PI (Proportional integrator) control for the buck converter completely neglecting using Pulse Width Modulation (PWM) direct way. [2] Shown experimental results on the MPPT when using the INC algorithm specified by a variable give good results, which could remedy the defect of the fixed step length of INC algorithm. The step length was changed by setting the threshold, and different threshold settings influenced the MPPT speed. In 2011, the high performance adaptive P&O algorithm based on power grid photovoltaic presented in [3], The oscillation at the point of maximum power for the P&O has improved by adaptive control functioning to change that P&O value according to

climate change in the system, in addition to tracing systems output capacity of the sun for dual and two-axis is higher than conventional support systems.

In general, follow the maximum power point of the PV system which is made by MPPT, thus depend on the algorithm and circuit, this circuit is a DC-DC converter which is considered as a variable resistance, the role of the algorithm is the mode between PV and the converter.

The P&O algorithm is widely used because of its low implementation complexity. The shortcoming of this algorithm is that the operating point of the PV fluctuates around the MPP. Therefore, the available energy is decreased. Furthermore, if the solar insolation changes rapidly, the P&O fails to track the real point of maximum power but has a drawback; the operating point oscillates around the MPP giving rise to the waste of a more or less significant amount of available energy.

The perturb oscillation around peak power point of P&O algorithm to track the peak power under fast varying insolation is overcome by INC Algorithm and Fuzzy controller . The INC and fuzzy can determine that the MPPT has reached the MPP and stop perturbing the operating point. In this paper demonstrate that fuzzy better than the INC, also applied proposed algorithm based on the system is the best, the algorithm is inspired by calculated on the system, the duty cycle was calculated based on the power, voltage and load, so the duty cycle does not change with perturbation, shows that this very efficient and very fast simple algorithm at the other.

The paper is organized as follows: after this introduction, the electrical model of PV system is presented. To prove the concept, a PV simulation based on one-diode model is explained. In the next section, a detailed description on the MPPT is given. The proposed

algorithm is described next. The three MPPT algorithms (FUZYY, INC and P&O) are presented respectively, as well as results simulation and analyze as described above are carried out in the following section. Finally, the conclusion is given.

II. Model of the solar cell

The photovoltaic cell is composed of a semiconductor material which absorbs light energy and converts it into electrical current. The solar cells are generally associated in series and in parallel, and then encapsulated in glass for a photovoltaic module. PV generator of inter connected modules to form a unit producing power continuous high compatible with the usual electrical equipment. The PV modules are usually connected in series-parallel to increase the voltage and current to the generator output. The interconnected modules are mounted on carriers metal and inclined at the desired angle depending on the location; this set is often referred module field [4, 5 and 6].

Thus the characteristic I-V PV generator is based on that of a cell elementary modeled by the equivalent circuit well known in Figure 1 [7, 8 and 9]. This circuitry introduces a current source and a diode in parallel, as well as series resistors R_s and parallel (shunt) R_P to reflect events dissipative at the cell level.
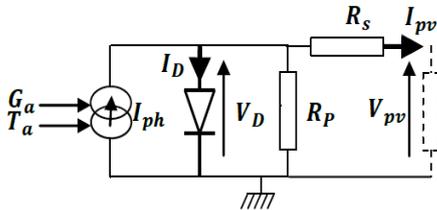

Figure 1. Equivalent electrical circuit of a solar cell

The series resistance is due to the contribution of the base resistors and the front of the junction and contacts the front and rear. The parallel resistance reflects the effects such as the leakage current through the edges of the cell is reduced because of the penetration of metal impurities in the junction (especially if this penetration is deep). This circuit can be used both for an elementary cell, for a module or a panel made up of several modules [10, 11].

The equation relating the current delivered by a solar cell and the voltage at its terminals is given by:

$$I_{pv} = I_{ph} - I_D + \frac{V_{pv} + R_s \cdot I_{pv}}{R_p} \tag{1}$$

Where I_{pv} and V_{pv} are respectively, the output current and the output voltage of the solar cell. The current passing through the diode is taken as:

$$I_D = I_0 \left(e^{\left(q \frac{V_{pv} + R_s \cdot I_{pv}}{K \cdot T_a} \right)} - 1 \right) \tag{2}$$

In addition, the photocurrent I_{ph} is also defined by:

$$I_{ph} = \frac{G_a}{G_n} [I_{sc} + K_I (T_a - T_n)] \tag{3}$$

Where T_a and T_n are respectively, the temperature condition of work and the one given at Standard Test Conditions (STC), i.e., $T_n = 25°C$. The difference between both temperatures is weighted by the coefficient, called also K_I. Moreover, G_a and G_n are respectively, the insolation condition of work and the one given at STC, i.e., $G_n = 1000 \, ^W/_{m^2}$.

Where I_0 is the reverse saturation current of the diode that given as:

$$I_0 = \sqrt[n]{\left(\frac{T_a}{T_n} \right)^3} * \frac{I_{sc}}{e^{\left(q \frac{V_{pv} + R_s \cdot I_{pv}}{K \cdot T_a} \right)} - 1} * e^{\left(\frac{q \cdot V_g}{n \cdot \left(\frac{1}{T_a} - \frac{1}{T_n} \right)} \right)} \tag{4}$$

Table 1 summarizes the meaning and the corresponding value of diverse electrical components. We get:

Table 1. Values used in equivalent electrical circuit.

Parameter	Quantity Identification (unity)	Corresponding Value
I_{sc}	Short-circuit current (A)	3.80
q	Elementary charge (c)	1.6×10^{-19}
K	Boltzmann constant (J/K)	1.38×10^{-23}
V_{oc}	Open-circuit voltage (V)	22.00
V_g	Energy gab (e-V)	1.20
n	the diode quality factor	1.2

In the PV panel, the actual output power is determined by three factors [12]: solar insolation, temperature and load. The following table contains some of the parameter values used in the simulation:

Table.2 The specification of PV system module used in the simulation.

Parameter	Value
Maximum Power P_{max}	*59.43W*
Maximum Voltage V_{max}	*18.00 V*
Maximum Current I_{max}	*3.30 A*
Number of cells	*36*

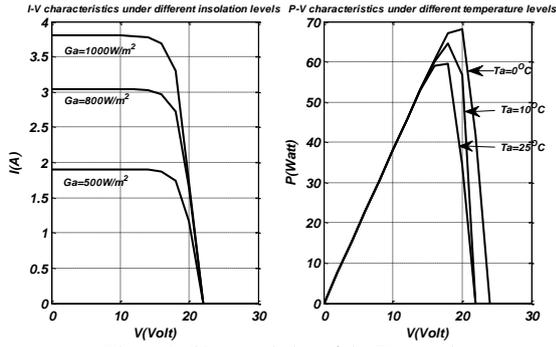Figure 2 shows *I-V* and *P-V* characteristics of the PV panel in different insolation and temperature conditions.

Figure 2. Characteristics of the PV panel

From the characteristics (*I-V*) shown in Figure 2, we can see that solar insolation affects the short-circuit current, also from the characteristics (*P-V*) in the same figure we can see that the temperature affects the voltage open circuit, these properties conclude that the production of energy in photovoltaic panel is heavily dependent on insolation and temperature that's mean the maximum power point changed, at the same time, the charge significant impact on the PV panel when weather conditions change. The only way to keep the system always works at maximum power point is to change the charge because the insolation and the temperature are uncontrolled variables. This is the MPPT role.

III.   Maximum Power Point Tracking

When the internal resistance (R_S) minutes of photovoltaic generator corresponds to the load resistance (R_L), giving the power delivered to the load is maximum illustrated in Figure 3.
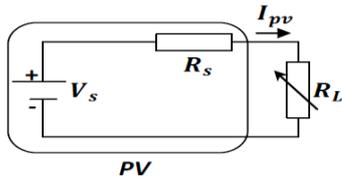

Figure 3. MPPT theorem: Equivalent Circuit

The resistance (R_S) is sensitive to sunlight, temperature, and other factors, so (R_L), should be adjusted to track the PV MPP is the role of a power converter for ($R_s = R_L$) illustrated in Figure 4.
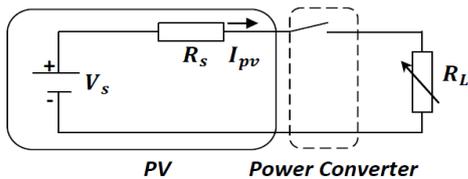

Figure 4. Role of power converter

Considering the way MPPT is find voltage V_{mpp} or

current I_{mpp} integrated mission planning for PV system should function to extract the maximum power P_{mpp} output under a certain temperature and insolation. Majority MPPT algorithms respond to changes in climate change parameters "insolation and temperature", others useful specifically if the temperature is almost constant and insolation varying. Generally, the MPPT is usually as Figure 5.
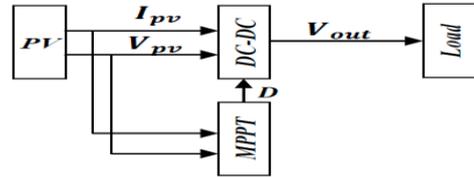

Figure 5. MPPT concept

III.1.   Proposed Algorithm

The duty cycle calculated by the MPPT controller will be introduced into the converter to keep close to the maximum power point regardless of the external circumstances of the change in temperature and insolation, and adjusting the voltage across the use of a DC-DC converter, which can help increase the efficiency of the photovoltaic panel [13].This type of converter is called Boost, where its electronic circuit, it composed of a switch S(mosfet, Implement insulated gate bipolar transistor(IGBT),…), inductor L, diode d and capacitors C_1 and C_2. It is powered by a voltage delivered by the PV and against this part; it feeds a resistive load R as illustrated in Figure 6.
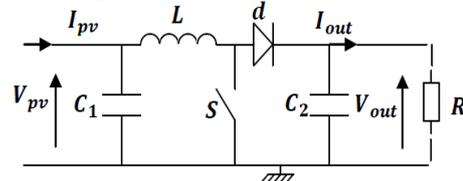

Figure 6. Circuit of the Boost converter

The voltage and current output of the boost is given by the following relations [6]:

$$V_{out} = \frac{V_{pv}}{1-D} \tag{5}$$
$$I_{out} = I_{pv} \cdot (1 - D) \tag{6}$$

The principle of the proposed algorithm is based on the calculation of the relationship between the duty cycle D, PV power, PV voltage and the load R .

According to Ohm's law:

$$R = \frac{V_{out}}{I_{out}} \tag{7}$$

We replace (5) and (6) to (7) we have:

$$R = \frac{V_{pv}}{I_{pv}(1-D)^2} \qquad (8)$$

Multiplying the numerator and denominator of equation (8) by the panel voltage V_{pv} , so the equation (8) becomes:

$$R = \frac{V_{pv}{}^2}{P_{pv}(1-D)^2} \qquad (9)$$

Simplified the equation (9) given the following equation for D:

$$D = 1 - \frac{V_{pv}}{\sqrt{P_{pv}*R}} \qquad (10)$$

The proposed algorithm steps as follows:

Step 01: Initialization $P_{pv} = 0$, $D = 0.5$ " selected (50%) in the probability that the optimum value in all cases is less than or greater than 0.5", R (arbitrary).
Step 02: Measure the voltage and current V_{pv}, I_{pv} calculate P_{pv} .
Step 03: Compare the actual power with the previous: If the two powers are different then calculate the new duty cycle from equation (10). If not: Save the same duty cycle D.
Step 04: A comparison D with extreme If $D > 0.99999$ then $D = 0.99999$ If $D < 0$ then $D = 0$.
Step 05: Replace P_{pv} and D by their current values.
Step 6: Return to Step 2 and re run the algorithm.

III.2. Fuzzy Logic Control

Fuzzy logic Control (FLC) of Photovoltaic Maximum Power Point Tracking Maximum power point tracking system uses boost converter to compensate the output voltage of the solar panel to keep the voltage at the value which maximizes the output power. MPP fuzzy logic controller measures the values of the voltage and current at the output of the solar panel, then calculates the power from the relation ($P_{pv} = V_{pv} \cdot I_{pv}$) to extract the inputs of the controller. The crisp output of the controller represents the duty cycle perturbation.

The FLC examines the output PV power at each sample time (k), and determines the change in power relative to voltage (dP_{pv}/dV_{pv}). If this value is greater than zero the controller change the duty cycle to increase the voltage until the power is maximum or the value (($dP_{pv}/dV_{pv} = 0$), if this value less than zero the controller changes the duty cycle to decrease the voltage until the power is maximum as shown in Figure 7.
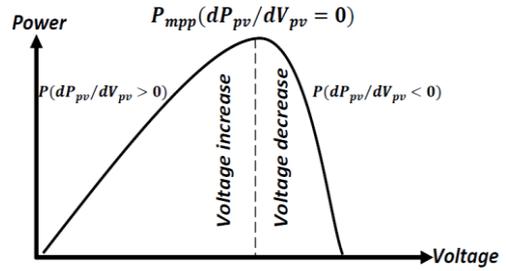

Figure 7. Power-voltage characteristic of a PV panel

FLC has two inputs which are: $Error$ and the $Change_{Error}$, and one output is the duty cycle perturbation ΔD. The two FLC input variables $Error$ and $Change_{Error}$ at sampled times k defined by [14]:

$$Error(k) = \frac{P_{pv}(k) - P_{pv}(k-1)}{V_{pv}(k) - V_{pv}(k-1)} \qquad (11)$$
$$Change_{Error}(k) = Error(k) - Error(k-1) \qquad (12)$$

Where:
$P_{pv}(k)$ is the instant power of the photovoltaic generator.

The input $Error(k)$ shows if the load operation point at the instant k is located on the left or on the right of the maximum power point on the PV characteristic, while the input $Change_{Error}(k)$, expresses the moving direction of this point. The fuzzy inference is carried out by using Mamdani method; FLC for the Maximum power point tracker contains three basic parts: Fuzzification, Base rule, and Defuzzification. A two-input (antecedent) rule of the Mamdani type has the form:
$if\ Error\ is\ x_1\ and\ Change_{Error}\ is\ x_2\ then\ \Delta D\ is\ x_3$

Where:
x_1, x_2 and x_3, are linguistic terms associated to the inputs and output variables ($Error$, $Change_{Error}$ and ΔD); the knowledge base defining the rules for the desired relationship is between the input and output variables in terms of the membership functions illustrated in Table 3. The choice of knowledge base by the assessment. Where many researchers use fuzzy as [15, 16]. This knowledge base resume how calculate duty cycle perturbation byt he $Error$ and the $Change_{Error}$ inputs.

Table 3. FLC rules.

$Change_{Error}$ / $Error$	NG	NP	EZ	PP	PG
NG	EZ	EZ	PG	PG	PG
NP	EZ	EZ	PP	PP	PP
EZ	PP	EZ	EZ	EZ	NP
PP	NP	NP	NP	EZ	EZ
PG	NG	NG	NG	EZ	EZ

Figure 8 illustrates the fuzzy set of *Error* and *Change$_{Error}$* inputs membership functions.
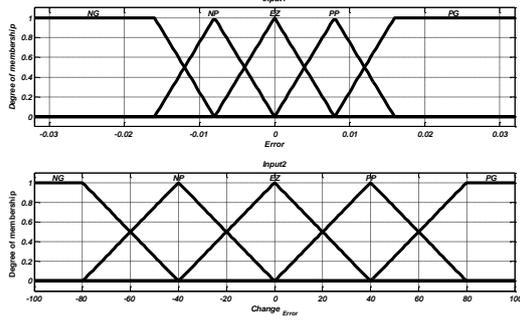

Figure 8. Membership functions of inputs

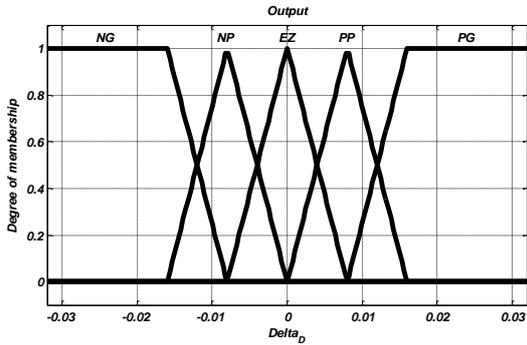Figure 9 illustrates the fuzzy set of the duty cycle output membership functions.

Figure 9. Membership functions of output

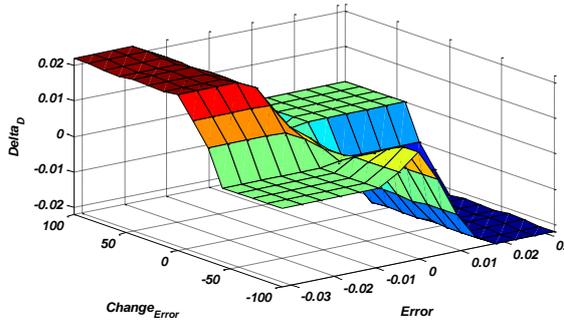Figure 10 shows the surface of the base rules using in FLC.

Figure 10. Rule surface of FLC

III.3. *Incremental Conductance Algorithm*

The criteria for the INC algorithm, reported by Wasynezuk [17], can then be given from the derivative of the power compared voltage:

$$\frac{dP_{pv}}{dV_{pv}} = 0 \overset{so}{\Rightarrow} V_{pv} \cdot dI_{pv} + I_{pv} \cdot dV_{pv} = 0 \overset{so}{\Rightarrow} \frac{dI_{pv}}{dV_{pv}} = -\frac{I_{pv}}{V_{pv}} \quad (13)$$

So:

$$\frac{\Delta I_{pv}}{\Delta V_{pv}} = -\frac{I_{pv}}{V_{pv}} \quad (14)$$

The algorithm relies on the measurement of current and voltage at specific moments in the same sample time. To calculate the duty cycle will depend on the equation (14) will calculate any change in the voltage thus (ΔV_{pv}) that did not pass teams to calculate the change in the current ((ΔI_{pv})). If this positive last here old duty cycle (*D*) will be added to it duty cycle perturbation (ΔD) where is a fixed value and therefore is a new duty cycle. But if it is not that, there will be a decrease in the duty cycle by the same value of perturbation to calculate the new duty cycle. That there has been a change in voltage in this case calculate the value represented in the equation (14) if it were positive in this case would be a decrease in the duty cycle but if that is where there is increase, and so forth [18].

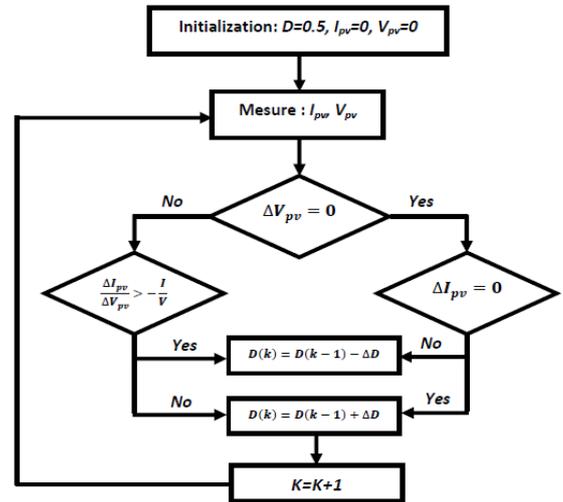The flow chart having the algorithm that is shown in Figure11:

Figure 11. Flow chart INC Algorithm

III.4. *Perturb &observe Algorithm*

The perturbation and observation (P&O) is a widely used approach in the search for MPPT because it is simple and requires only measures voltage and current of the PV module V_{pv} and I_{pv} respectively, its name suggests, the method works with P&O disturbance voltage Vpv respectively, it can track the maximum power point.

Figure 12 shows the shortened flowchart of the P&O algorithm. At each cycle, V_{pv} *(k)* and I_{pv} *(k)* are measured to calculate $P_{pv}(k)$. $P_{pv}(k-1)$ value calculated in the previous cycle by V_{pv} *(k-1)* and I_{pv} *(k-1)*. So the P&O work to generate the best duty cycle [14, 20 and 21].
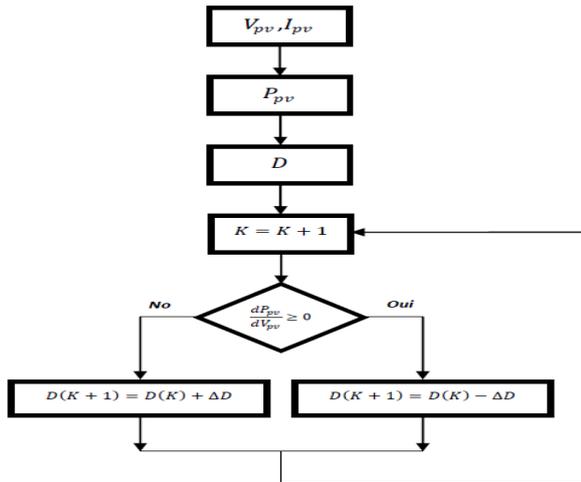
Figure 12. Flow chart P&O Algorithm

IV. System Configuration and Simulation Results

IV.1. Modeling and Simulations

MPPT-PV system is installed on the tool of simulation ***Matlab/Simulink*** considered as a good test, it shown in Figure 13. The general system comprises a PV module and boost converter, so that PV module was created as the mathematical model of Figure 1.The PV has the characteristics of table1. The variation of insolation illustrated in Figure 14 and the temperature fixed at 25 ° C, the boost parameters are as follows: $L = 350 \times 10^{-6}H$, $C_1 = C_2 = 560 \times 10^{-6}F$, $R = 20\Omega$.
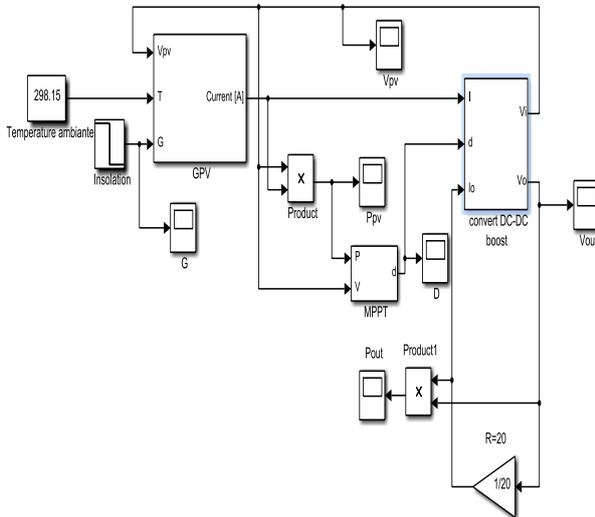

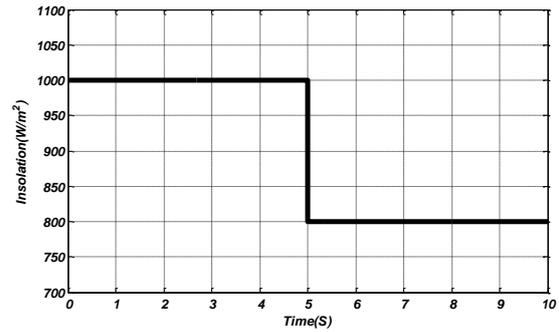Figure 13. The configuration of the PV-based system

Figure 14. Rapidly change insolation

Other times to validate the operation of the algorithm proposed consider the daily evolution of the solar insolation, considered this evolution is in cloche shape shown in Figure15.
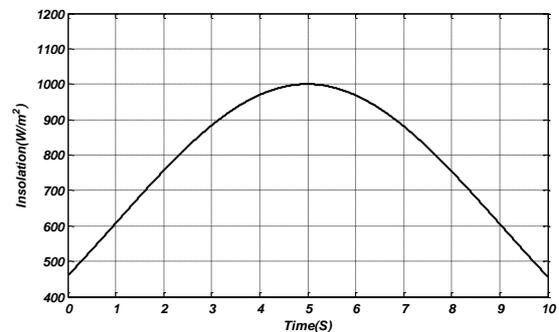

Figure 15. Cloche shape insolation

IV.2. Analysis of Simulation Results:

In order to test the effectiveness of the improvement, four MPPT algorithms (the P&O algorithm, the INC algorithm, the fuzzy controller and the proposed algorithm) are simulated on the PV system built in MATLAB. Given the rapidity and the accuracy of the simulation, the simulation time is 10s, and zero-order holds of the MPPT module has sampling period of 0.01s. Simulation results of four MPPT algorithms under sudden insolation change from 1000W/m2 to 800W/m2 at t=5s. Simulation results show that:
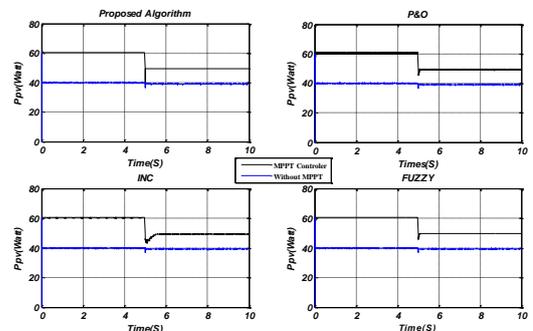
Figure16 shows the P_{pv} with and without MPPT.

Figure16. Simulation results of P_{pv} with and without MPPT algorithms

Figure17 illustrates clearly the effectiveness of each algorithm exactly in the rapid change of the insolation.
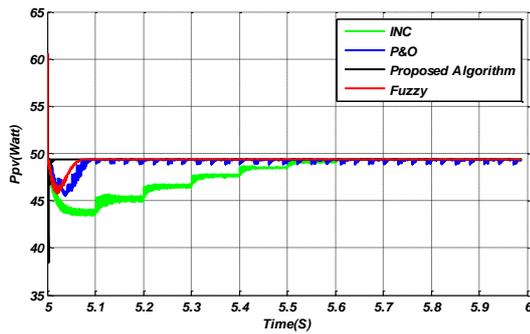

Figure17. P_{pv} illustrated exactly in the change of insolation
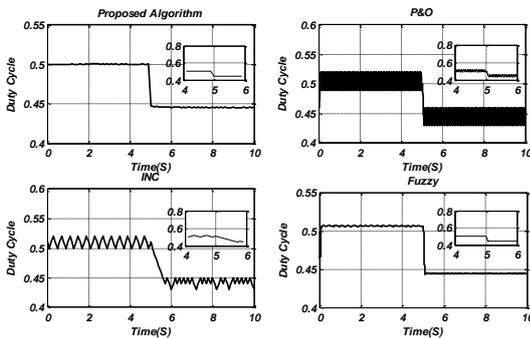
Figure 18 shows the optimum duty cycle.

Figure18. The optimum duty cycle

Figure 19 shows the P_{pv} where applying the proposed algorithm for cloche shape insolation.
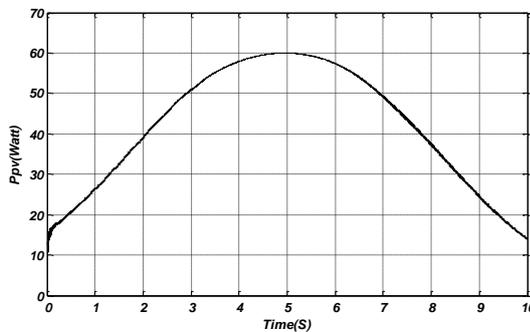

Figure 19. P_{pv} using cloche shape insolation applying proposed algorithm

From the results obtained, we can note:
- The energy increased by the MPPT algorithms,
- All MPPT algorithms have a good dynamic response as three controllers could reach a steady state within 5s after the isolation changes rapidly except the INC algorithm, and proposed algorithm makes the system track the MPP more rapidly,
- The P&O algorithm made a misjudgment when isolation changes rapidly, but the others algorithms overcome this drawback

of the P&O algorithm. We observed that the proposed algorithm is the best,
- The PV panel with the MPPT proposed algorithm gives a good matching between the panel and the dc load under cloche shape insolation.

V. Conclusion

MPPT algorithm of the PV system is proposed in this paper. The traditional P&O algorithm shows a good dynamic response but poor stability and misjudgment. Therefore the INC algorithm and the fuzzy controller are introduced to overcome these drawbacks, and the proposed algorithm is introduced to calculate the optimum duty cycle where has relationship with the power, the voltage and the load. The result shows that The PV system with the MPPT gives a good matching between the panel and the dc load under various operating conditions, also it could reach the MPP rapidly, show better steady state performance and make no misjudgment. All in all, the proposed algorithm exhibits better overall performance than the P&O algorithm in both transient and steady-state response.

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