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Maximum Power Point Tracking Using Adaptive Fuzzy Logic control for Photovoltaic System

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ABSTRACT
This work presents an intelligent approach to the improvement and optimization of control performance of a photovoltaic system with maximum power point tracking based on fuzzy logic control. This control was compared with the conventional control based on Perturb &Observe algorithm. The results obtained in Matlab/Simulink under different conditions show a marked improvement in the performance of fuzzy control MPPT of the PV system.
***Keywords* -** DC-DC converter, fuzzy logic, MPPT, perturb and observe, Photovoltaic.

I. INTRODUCTION

Solar energy is one of the renewable energy that has the greatest potential for development. Our work is part of the commitment of our country to exploit these renewable and non-polluting natural resources for the development of photovoltaic plants. The PV array consists of photovoltaic panels, a power interface and a load. A DC /DC converter (boost) ordered to pursue the maximum power point tracking (MPPT) and photovoltaic modules were developed in Matlab/ Simulink.

Many conventional methods have been widely developed and implemented to track the maximum power point as incrementing the conductance and Perturb & Observe... [1] That exhibit oscillations around the MPP (maximum power point) at search of maximum power point.

The proposed fuzzy control gave a very good performance. He improved the responses of the photovoltaic system, it not only reduces the response time for the continuation of the maximum power point but it also eliminated the fluctuations around this point. This shows the effectiveness of the fuzzy control for photovoltaic systems in stable environmental conditions and changing (where the light vary over time). The results for the energy conversion show that with the fuzzy logic control, there is a compromise between speed and stability in transient steady state.

II. DESCRIPTION ON THE SYSTEM

The block diagram of a PV system that feeds a resistive load (RS) is shown in Figure 1.

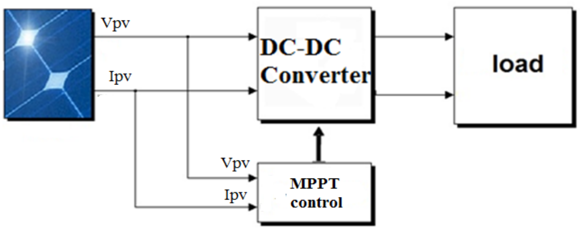

Figure 1: Block diagram of the PV system with a MPPT Control

The PV array consists of 5 PV modules connected in parallel and 5 connected in series, the characteristics ofCS5P-220M PV module used are shown in table 1.

Boost converter for generating a variable DC voltage source from a source of fixed voltage, it consists of capacitors, inductors and switches. All these devices ideally consume no power that is why the boost converter has a good performance. Usually the switch is a MOSFET transistor which is a semiconductor device which operates in (locked-saturated) [2].

The MPPT algorithm for searching the optimal operating point of the PV generator according to the climatic conditions (temperature, irradiation).

Parameters	**Values**
Maximum power at acceptable insolation level 1000 W/m^2	219.72 W
Maximum power voltage	48.3159 V
Maximum power current	4.54758 A
Short circuit current	5.09261 A
Series resistance of PV model	0.24807 ohm
Parallel resistance of PV model	235.76 ohm
Diode saturation current	5.3103e-07 A
Diode quality factor	1.5

Table1: Simulation parameters and values.

III. BOOST CONVERTER MODEL

For a PV system connected to a resistive load there is a necessity to insert a boost type converter [3], presented in Figure.2, that will use a certain controller in order to maintain the maximum power. The system is written in two sets of state equation that are depending on the position of switch SW. If it is in position ON (SW=0), the differential equation is:

$$\begin{cases} i(t) = \dfrac{1}{L}\displaystyle\int v_{in} - v_{out} \\ v_{out} = \dfrac{1}{C}\displaystyle\int (i - \dfrac{v_{out}}{Rload}) \end{cases} \quad (1)$$

If the switch SW is in position "1"2), SW=1, the differential equation is expressed as:

$$\begin{cases} i(t) = \dfrac{1}{L}\displaystyle\int v_{in}dt \\ v_{out}(t) = \dfrac{1}{C}\displaystyle\int -\dfrac{v_{out}}{R_{load}} \end{cases} \quad (2)$$

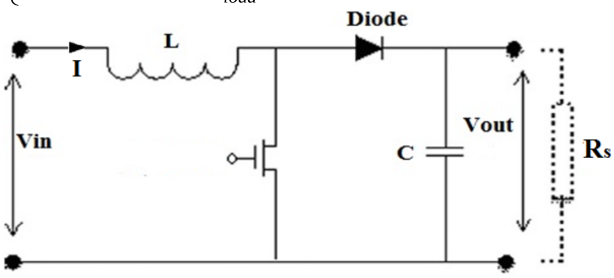

Figure 2: The boost DC/DC converter

IV. MAXIMUM POWER POINT TRACKING

A PV array is generator whose characteristic I = f (U) is highly nonlinear. Accordingly, for a same illumination, the power delivered will be different depending on the load. MPPT controller makes it possible to control the power converter connecting the charge (a battery, for example) and solar panel to continuously provide maximum power to the load. From this rule and the type of controller, there are several and different methods to extract the maximum power [4] [5].

V. FUZZY LOGIC CONTROL

Fuzzy logic is an extension of Boolean logic which offers a very valuable contribution to the reasoning that uses flexibility, making it possible to take account of inaccuracies and uncertainties. Its main advantages are its linguistic description and independence of mathematical model. A fuzzy logic control consists of four steps: fuzzification, knowledge base, inference mechanism and defuzzification [6] [7]. The fuzzification corresponds to the linguistic variables. The knowledge base is composed of a database and a base of rules designed to achieve good dynamic response function of external perturbations of the PV system.

- The inference mechanism uses a collection of linguistic rules to convert the input into an output conditions fuzzified.
- The defuzzification is used to convert the fuzzy output control signals.

For this work, triangular shaped membership function has been chosen. The range of the signal has been selected by checking the oscillation of each signal. Figure.3 represents the graphical view of the membership function for error, change of error, and duty cycle of the fuzzy logic control. Figure 4 shows the block view of the fuzzy logic algorithm in Simulink window. Five linguistic variables (NB, NS, ZE, PS, PB) are adopted for each of the three input/output variables. Where NB stands for Negative Big and NS: Negative Small, ZE: Zero, PS: Positive Small, PB: Positive Big, The fuzzy rules are summarized in Table.2.

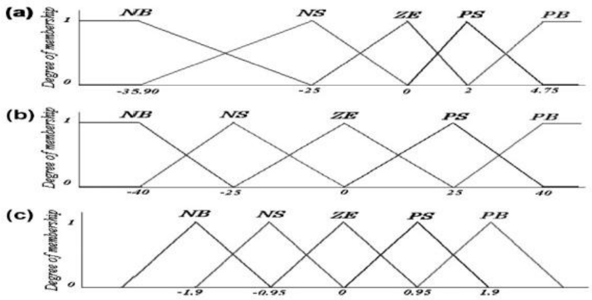

Figure 3: Membership functions for inputs and output of Fuzzy Logic Control

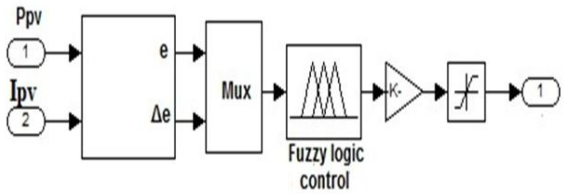

Figure 4 Model of fuzzy logic control

e \ Δe	NB	NS	Z	PS	PB
NB	NB	NB	NB	NS	Z
NS	NB	NS	NS	Z	PS
Z	NB	NS	Z	PS	PB
PS	NB	Z	PS	PB	PB
PB	Z	PS	PB	PB	PB

Table 2: Table of fuzzy logic control rules

The fuzzy control algorithm is implemented to control the load phase current based on processing of the:

$$P_{pv}(K) = V_{pv}(K) * I_{pv}(K) \quad (3)$$

$$e(K) = \frac{P_{pv}(K) - P_{pv}(K-1)}{I_{pv}(K) - I_{pv}(K-1)} \quad (4)$$

$$\Delta e(K) = e(K) - e(K-1) \qquad (5)$$

$$dD = \frac{\sum_{j=1}^{n} \mu(D_j) - D_j}{\sum_{j=1}^{n} \mu(D_j)} \qquad (6)$$

If e is PB and Δe is Z then dD is Z.

This means that if the operating point is far from the maximum power point to the left side, and the change in the slope of the curve (Ppv = f (Vpv)) is approximately zero; then keep the same duty cycle (dD) as Figure 5 shows.

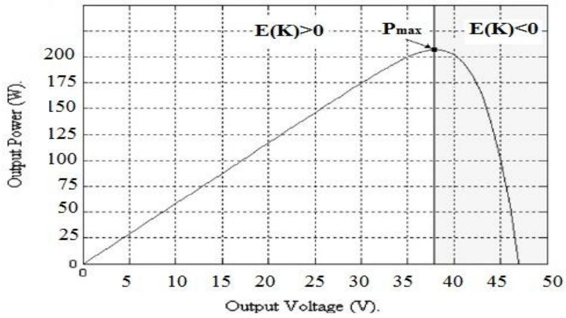

Figure 5: Slope characteristics of the PV curve at different points

VI. SIMULATION RESULTS AND DISCUSSIONS

The theoretical analysis of the proposed MPPT technique is to be validated and is done by simulation using MATLAB/SIMULINK platform. The simulink model of the PV system with fuzzy logic control is shown in Figure. 4 describe the subsystem model of the fuzzy logic control.

The two systems are simulated in combination with the DC / DC converter under stable environmental conditions and then with a rapid variation of solar insolation.

6.1. Operation under constant conditions

In this test the temperature and insolation are kept constant. It takes the values of standard test conditions (STC) (T= 25 ° C and solar insolation G =1000W/m2). The purpose of these simulations is to visualize the shift of the operating point from point MPP. It also serves to evaluate losses oscillations around this point. Figure 6 presents the way that the voltage, which is generated by the source, changes related to the converters duty cycle until it reaches the value which corresponds to the maximum power point. Figures 7-8 shows the maximum current and power generated by the PV field. Figures 11-12 shows the regulated voltage Vdc of boost converter and the Photovoltaic field characteristics Ppv-Vpv.

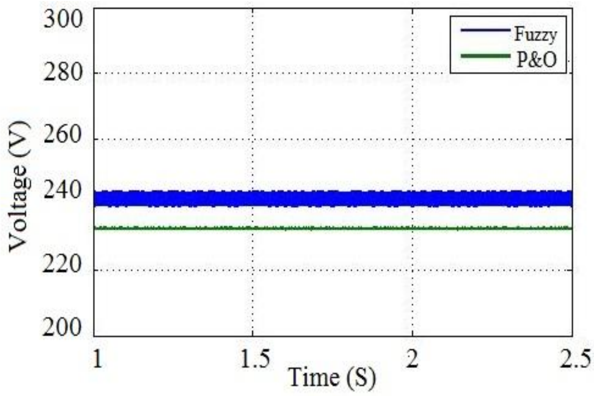

Figure6: Output voltage of photovoltaic system

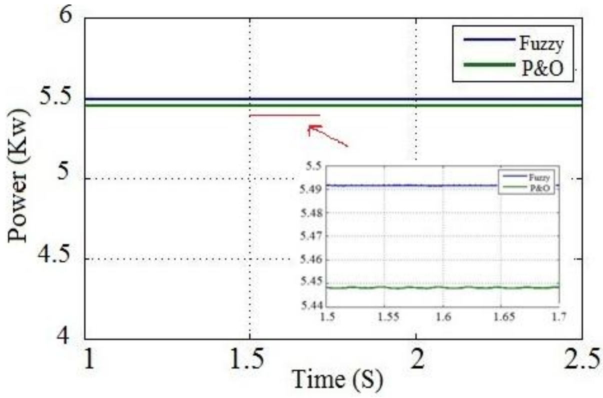

Figure7: Photovoltaic output power

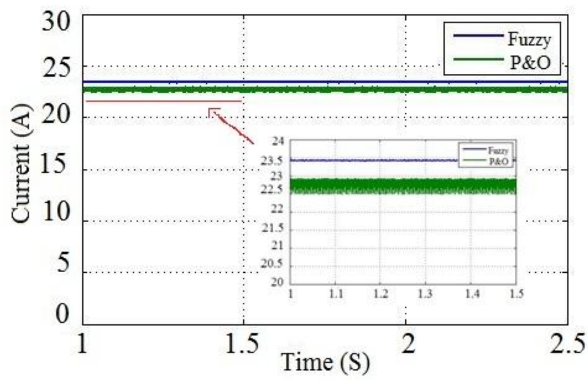

Figure8: Output current of photovoltaic system

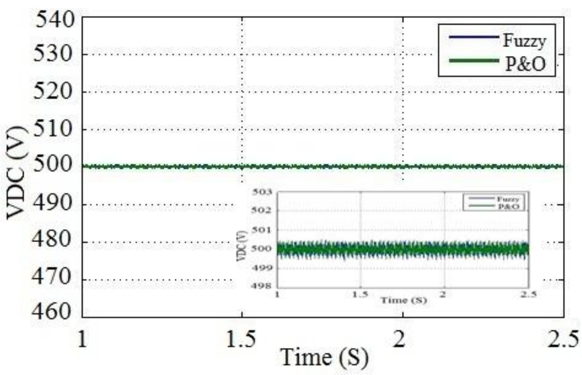

Figure9: Regulated voltage Vdc of boost Converter

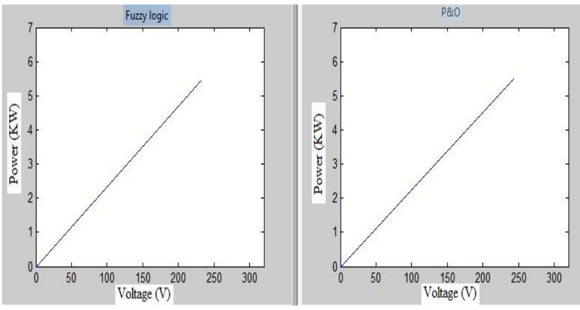

Figure10: Photovoltaic field characteristics Ppv-Vpv

6.2. Behavior of the system to change of illumination

The settling time of PV system is analyzed at solar insolation value of 1000W/m2 and 800 W/m2. It is observed that with the proposed fuzzy logic controller, the PV system exhibits a faster response. With the change in the solar insolation value, the maximum power point (MPP) changes. After 0.5 s, the solar insolation changes rapidly up to 250W/m2 shown in figure 11.

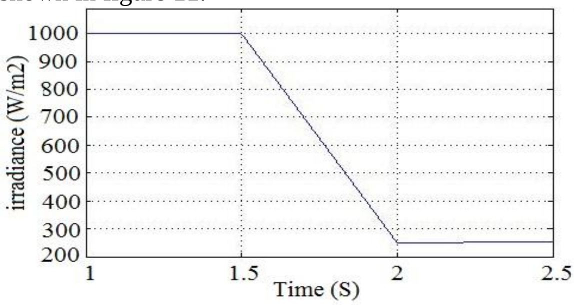

Figure11: Irradiation variation

The same performance is observed with the proposed controller. However, the P&O algorithm turns out with a drop in its characteristics. It is clear that the MPP is reached very rapidly and the dynamic performance of PV system is highly improved when compared with the conventional P&O algorithm.

Whenever there is a change in insolation, the P&O algorithm produce oscillations around the operating points with reduced power output. In addition, this technique is slow to cover the optimal point and may fail to track the peak power for rapidly changing solar insolation conditions.

Hence, the total tracking performance of the system gets affected. The output of the proposed controller provides stable PV current as per the changes of power and voltage. The proposed controller based PV system tracked maximum power which is comparable with P&O.

Figures 12-14 shows respectively the effect of change of insolation on the voltage, current, power delivered by the photovoltaic field with two controllers (P&O and fuzzy logic controller) under the temperature 25°C. Figure 15 shows the regulated voltage Vdc of the boost converter. Figure 16 show the photovoltaic field characteristics Ppv-Vpv.

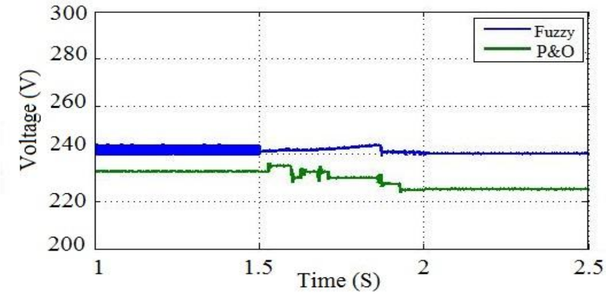

Figure12: Output voltage of photovoltaic system

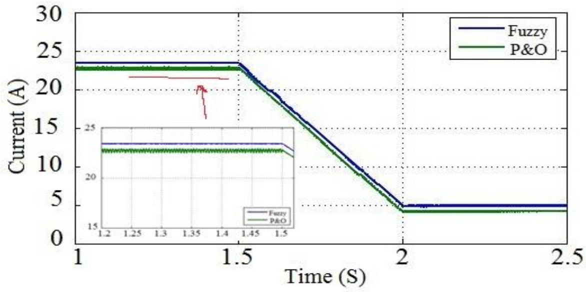

Figure13: Output current of photovoltaic system

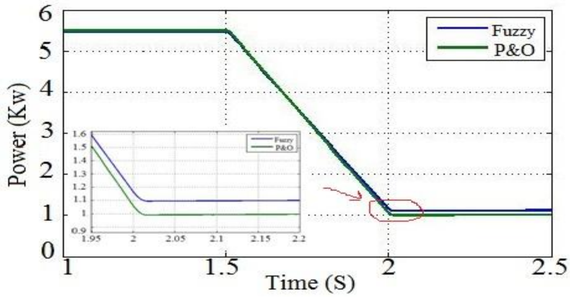

Figure14: Photovoltaic output power

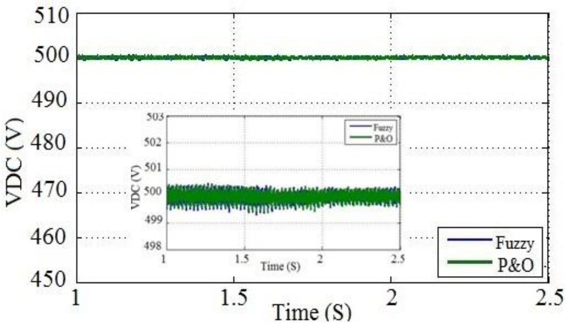

Figure15: Regulated voltage vdc of boost converter

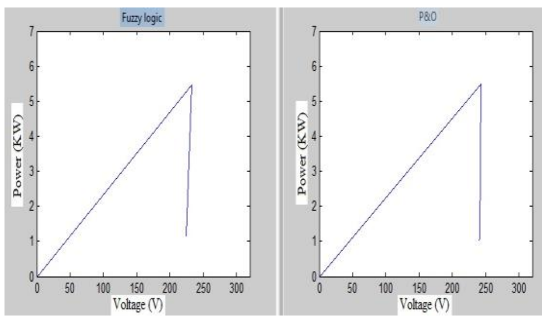

Figure16: Photovoltaic field characteristics Ppv-Vpv

VII. CONCLUSION

This paper presents an algorithm of the photovoltaic array maximum power point tracking which is based on fuzzy logic.The different results with different robustness test confirms the proper operation of fuzzy control with good performance in the atmospheric variations of illumination and temperature there by reducing power losses, with better dynamics results. The fuzzy control pursues with satisfaction at the sharp variations of irradiations with a fast response time. This eliminates the fluctuations in the power, voltage and duty ratio in steady state. The fuzzy logic control is more effective for the nonlinear systems because it is more flexibility.

A fast and stable fuzzy logic controller MPPT has been obtained, the latter has proved that it guaranties better performance, faster response time; moreover, it has proved its robustness to different climatic variations.

REFERENCES

[1] **[**R. R. Hernandez, S. B. Easter, M. L. Murphy- Mariscal, F. T. Maestre, M. Tavassoli, E. B. Allen, C. W. Barrows, J. Belnap, R. Ochoa-Hueso, S. Ravi, et M. F. Allen, « *Environmental impacts of utility-scale solar energy* », *Renew. Sustain. EnergyRev*., vol. 29, p. 766‑779, janv. 2014.

[2] Chemanedji et A. Sadoud, "*Conception d'un Hacheur à deux Thyristors Auxiliaires Destiné à la Poursuite du Point de Puissance Maximale d'un Générateur Photovoltaïque*", *Rev. Energ. Ren*. : Valorisation (1999) 109-112.

[3] H. De Battista et R. J. Mantz, « *Variable structure control of a photovoltaic energy converter* », *Control Theory Appl. IEE Proc*. -, vol. 149, no 4, p. 303‑310, 2002.

[4] M.F. Yaden, M. El Ouariachi, T. Mrabti , Ka. Kassmi, B. Tidhaf, E. Chadli et K. Kassmi "*Conception et réalisation d'un système photovoltaïque muni d'une commande MPPT numérique*" *Revue des Energies Renouvelables* Vol. 14 N°1 (2011) 171 – 186

[5] BEN HAMED M., SBITA L., FLAH A., ABID A. and GARRAOUI R., "*A real time implementation of an improved MPPT controller for photovoltaic systems* ", *Renewable Energy and Vehicular Technology (REVET), 2012 First International Conference on, Hammamet, Tunisia*, pp. 173 – 178, March 2012.

[6] E. Koutroulis, K. Kalaitzakis, et N. C. Voulgaris, « *Development of a microcontroller-based, photovoltaic maximum power point tracking control system* », *IEEE Trans. Power Electron.*, vol.16, no 1, p. 46‑54, 2001.

[7] H. Buhler, Réglage Par Logique Floue, *Presses Poly-techniques et Universitaires Romandes CH-1015 Lau-sanne*. 1994.

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