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Indirect hybrid fuzzy-P&O variable step size MPTT controller improving performances under fast changing atmospheric conditions

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Abstract - *In this paper, an indirect hybrid fuzzy-P&O variable step size MPPT controller has been proposed. The classical fixed step P&O MPPT algorithm is the most widely used due to its simplicity and easy implementation. However, this algorithm presents several low performance and steady state oscillation around the MPP affecting the convergence speed and prone to failure especially in fast changing atmospheric conditions. To overcome these drawbacks, the proposed MPPT controller uses the conventional P&O MPPT algorithm where the step size is drived using a fuzzy logic controller. The proposed controller is tested and validated under Matlab/Simulink environment where the entire model of the PV system including a Solarex MSX-60W module fed by DC-DC boost converter drived using the proposed hybrid fuzzy-PO MPPT controller is implemented. Result are presented showing a good improvement of the MPPT performances in dynamic and steady state responses.*

Résumé - *Dans cet article, nous proposons un contrôleur MPPT indirect hybride flou-P&O à pas variable. L'algorithme MPPT P&O classique à pas fixe est le plus utilisé pour sa simplicité et sa facilité d'implémentation. Néanmoins, cet algorithme présente de faibles performances et des oscillations en régime permanent autour du point MPP affectant la vitesse de convergence causant sa possible divergence spécialement, quand il est soumis à des variations rapides des conditions atmosphériques. Pour surmonter ces faiblesses, l'algorithme proposé utilise l'algorithme P&O conventionnel dont le pas est guidé par un contrôleur flou. Le contrôleur proposé est testé et validé sous l'environnement Matlab/Simulink où l'ensemble du modèle du système PV incluant un module Solarex MSX-60W connecté à un convertisseur DC-DC de type élévateur piloté par le contrôleur MPPT flou-P&O est implémenté. Les résultats montrent une bonne amélioration des performances du contrôleur MPPT dans les deux régimes transitoire et permanent.*

Mots clés: P&O - Contrôleur MPPT - Logique floue - Modélisation de la cellule photovoltaïque - Pas variable.

1. INTRODUCTION

The melting of the glaciers, the Fukushima nuclear catastrophe, the rise of the ocean levels and the increase of the weather extremes, all show clearly that the present method of generating energy has no future due to finiteness of resources reflected in the rising prices of oil and gas as well as the first effects of burning fossil fuels. The interest in the

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use of so-called green experiencing an unprecedented boom. These use infinite sources as a basis for energy supplies and can ensure a full supply with a suitable combination of different technologies such as biomass, photovoltaic, wind power, etc. A particular role in the number of renewable energies is played by photovoltaics. They permit an emission-free conversion of sunlight into electrical energy and will be an important pillar in future energy systems [1].

Photovoltaic is a technology involving the direct conversion of solar radiation (insolation) into electricity using solar cells. Interest in photovoltaic has grown exponentially in many countries over the past decade, with worldwide photovoltaic sector growth since 1997 ranging from 30 to 85 %. The main advantages of photovoltaic systems are [2]:

- Their fuel is abundant and free;
- The photovoltaic energy contributes to the decarbonisation and preservation of natural resources;
- Photovoltaic solar panels are recyclable;
- The photovoltaic processes are completely self-contained;
- There are no moving parts and no materials consumed or emitted;
- They may be combined with other power sources to increase system reliability;
- They can withstand severe weather conditions, including cloudy weather;
- They can be installed and upgraded as modular building blocks; more photovoltaic modules may be added as power demand increases.

Despite the large number of photovoltaic advantages, the efficiency of a PV plant still presents some drawbacks comparing to conventional energy resources, it is affected by three factors: the efficiency of the PV panel which is only in the range of 9 - 17 %, the efficiency of the converter/inverter and the efficiency of the MPPT algorithm.

The efficiency of the PV panel and the converter/inverter is not easy to improve as it depends on the available technology. Improving the tracking of the MPPT stage using new control algorithms is the easiest and not expensive way that leads to an increase in the PV power generation [3-5].

In this spirit, the last two decades have seen a craze for new developments of MPPT control strategies: Perturbation and observation (P&O) [6, 7], Incremental Conductance (IC) [8, 9], Fractional Open-Circuit Voltage (FOCV) [10, 11], Fractional Short-Circuit Current (FSCC) [12, 13], Hill Climbing (HC) [14, 15], Neural network (NN) [16, 17], Fuzzy logic [18, 19], Genetic algorithms (GA) [20, 21], particle swarm optimization (PSO) [22, 23], etc. Among all the previous MPPT strategies, the P&O algorithm is the widely employed due to easy implementation and simplicity.

Conversely the performance depends essentially to the fixed step size: a larger step size will lead to faster dynamics and a higher value of oscillation amplitude around the peak point; and small step size will reduce the steady state oscillations at the expense of a slow tracking speed and a risk of divergence in case of rapidly changing atmospheric conditions. Hence, the trade off between the dynamics and steady state accuracy must be established by the corresponding design.

In this paper, an indirect hybrid fuzzy-PO variable step size MPPT controller is proposed to provide the duty cycle under different atmospheric conditions. The proposed MPPT uses the conventional PO MPPT algorithm here the step size is drived using a fuzzy logic controller. The proposed fuzzy-PO variable step size MPPT controller is tested and validated using Matlab/Simulink model for different atmospheric conditions. Results are presented showing a good improvement of the MPPT performances.

The remainder of the paper is organized as follows. In Section 2, the photovoltaic cell modeling is presented. Section 3 describes the proposed fuzzy-PO variable step size MPPT. Section 4 presents the simulations results and discussions. While Section 5 draw the main conclusions of this work.

1. MODELING OF PV CELL

The well-known and widely used model based on the well-known Shockley diode equation is presented below figure 1 [24].

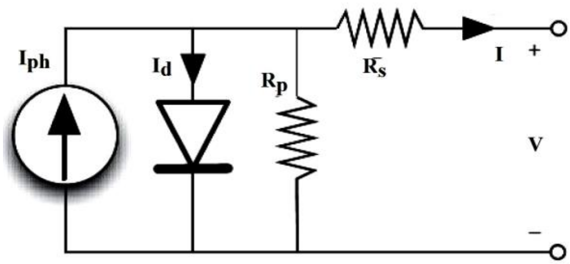

Fig. 1: Solar cell single-diode model

The output current I can be expressed by:

$$I = N_p I_{ph} - N_p I_{rs} \left(e^{\left(\frac{q(v+R_S I)}{AkTN_S} \right)} - 1 \right) - N_p \left(\frac{q(v+R_s I)}{N_s R_p} \right) \qquad (1)$$

where, V is the cell output voltage; q is the electron charge (1.60217646×10^{-9} C); k is the Boltzmann's constant (1.3806503×10^{-23} J/K); T is the temperature in K; I_{rs} is the cell reverse saturation current; A is the diode ideality constant; N_p is the number of PV cells connected parallel; N_s is the number of PV cells connected in series.

The generated photocurrent I_{ph} is related to the solar irradiation by the following equation

$$I_{rs} = I_{rr} \left(\frac{T}{T_r} \right)^3 \exp\left(\frac{qE_g}{kA} \left(\frac{1}{T_r} - \frac{1}{T} \right) \right) \qquad (2)$$

Where, E_0 is the band-gap energy of the semi-conductor; I_{rr} is the reverse saturation at T_r.

2. PROPOSED HYBRID FUZZY-PO VARIABLE STEP SIZE MPPT

The MPPT control the voltage to ensure that the system operates at maximum power point on the PV curve by adjusting the duty cycle of the PWM generator as shown in figure 2.

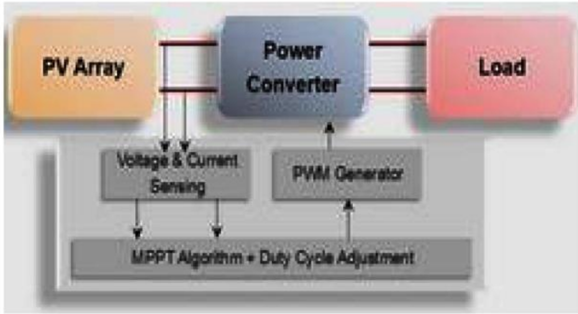

Fig. 2. PV system with MPPT controller

2.1 Conventional fixed step size P&O MPPT

Perturb and Observe MPPT is the most widely used algorithm. It involves perturbation of the operating voltage or the duty cycle based on a comparison of the generated power to ensures maximum power point. The principle is very simple: in the ascending phase of the $P-V$ curve and considering a positive change of the voltage, the tracker generates a positive voltage increasing as a consequence the delivered PV power and change of the operating point X_i $(i=1;2;\ldots;n-1)$.

In this case, the PV voltage and power increase up to a new point X_{i+1}. Similar steps with opposite direction can be done in the case of a decrease in the PV power; the instantaneous PV voltage follows the maximum power point according to a predetermined PV voltage and power values.

Under these conditions, the tracker seeks the MPP permanently. At specified PV voltage, the desired power is the solution of the nonlinear equation given by $(dP/dV = 0)$ as shown in figure 3.

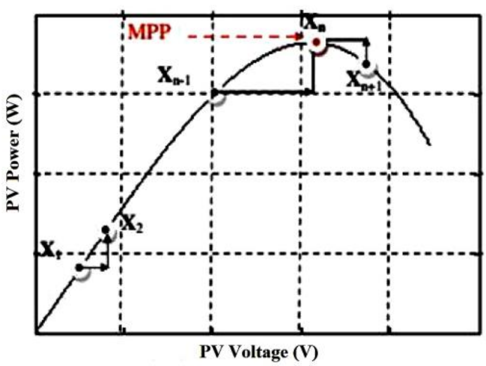

Fig. 3: P&O algorithm principle

However, the magnitude of the step size is the main factor determining the amplitude of oscillations that allows the convergence rate to the final response. Using a larger disturbance will lead to a higher value of oscillation amplitude around the peak point.

Using small step size will reduce the steady state oscillations at the expense of a long response time and a risk of divergence in case of rapidly changing atmospheric conditions [18]. The flowchart of the P&O algorithm is illustrated in figure 4.

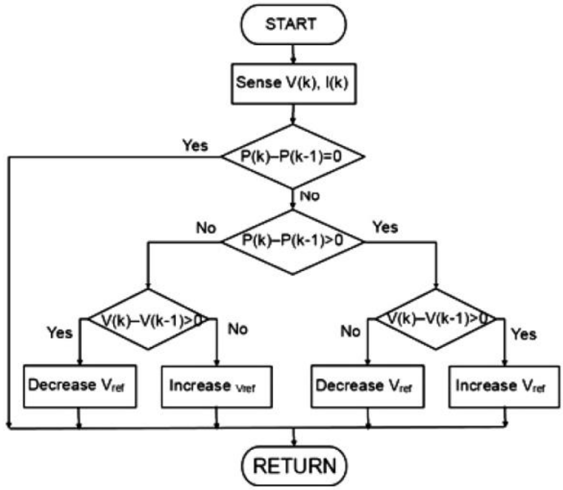

Fig. 4: Fixed step size P&O algorithm flowchart

2.2 Fuzzy logic controller

Fuzzy logic have the benefits of operating with general inputs instead of a correct mathematical model and handling nonlinearities mathematical logic management typically consists of four stages: fuzzification, rule base, inference method, and defuzzification [25, 26]. In this study, the proposed fuzzy MPPT requires as inputs the error E and the change in error ΔE defined by:

$$E_k = \frac{P(k) - P(k-1)}{V(k) - V(k-1} \tag{3}$$

$$\Delta E_k = E_k - E_{k-1} \tag{4}$$

where, $I(k)$ and $I(k+1)$ are the current at instant k and $k-1$; $V(k)$ and $V(k+1)$ are the voltage at instant k and $k-1$.

The output is the fuzzy scaling (FS) of the PWM duty cycle step variation Δd.

Fuzzification- The universe of discourse for input variables (E_k and ΔE_k) as well as for the output variable (Δd) is divided into seven fuzzy set s: PB (Positive Big), , PS (Positive Small), Z (Zero), NS (Negative Small), and NB (Negative Big).

Rules base- The Fuzzy algorithm tracks the MPP based on the rule-base consisting of 25 rules as shown below:

Table 1: Fuzzy rule base

ΔE_k \ E_k	**NB**	**NS**	**ZE**	**PS**	**PB**
NB	ZE	ZE	PS	NS	NB
NS	ZE	ZE	ZE	NS	NB
ZE	PB	PS	ZE	NS	NB
PS	PB	PS	ZE	ZE	ZE
PB	PB	PS	NS	ZE	ZE

Inference method- In this study, we use the Mamdani's inference system is utilized with the maximal creation strategy [28].

Defuzzification- We use the centroïd method considered as one of the normally utilized defuzzification routines.

3.3 Proposed combined fuzzy-PO variable step size MPPT

The performances of MPPT controller depends mainly on the step size. Therefore, a good calculation of step size provides a high performance of MPPT controller and as a consequence the performances of the PV systems. The proposed variable step size for the hybrid fuzzy-PO MPPT algorithm is given as follows:

$$D(k) = D(k-1) + FS + AD \quad (6)$$

Where, $D(k)$ and $D(k-1)$ are the duty cycle at instants k and $k+1$; FS is the scaling factor adjusted at the sampling period; AD is the fixed step size.

3. RESULTS AND DIDCUSSIONS

The effectiveness of proposed indirect hybrid fuzzy-PO variable step size MPPT controller is investigated by implementing the model of the entire system using Matlab/Simulink software, composed of Solarex MSX-60 W PV panel operating at variable atmospheric conditions (Table II) and DC-DC boost converter drived using the propose fuzzy-PO MPPT controller (figure 5).

Table 2: Electrical characteristics of Solarex MSX - 60 (1 kW/m^2, 25°C) [28]

Description	MSX-60
Maximum power, P_{MPP}	60 W
Voltage at P_{max}, V_{MPP}	17.0 V
Current at P_{max}, I_{MPP}	3.5 A
Short circuit current, I_{sc}	3.8 A
Open circuit voltage, V_{oc}	21.1 V
Temperature coef. of V_{oc}	-(80±10) mW/°V
Temperature coef. of I_{sc}	(0.065±0.01) % °C
Temperature coef. of power	(-0.5±0.05) % °C
NOCT	47.2 °C

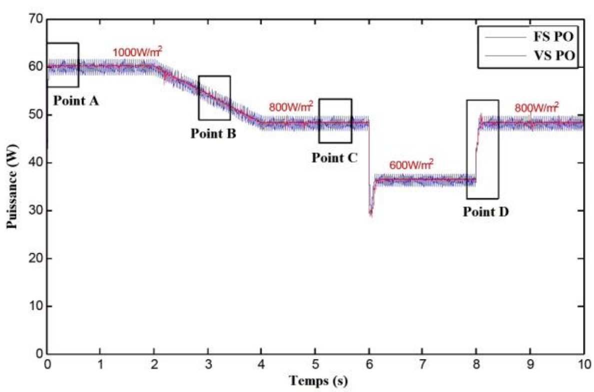

Fig. 6: Output Power tracking

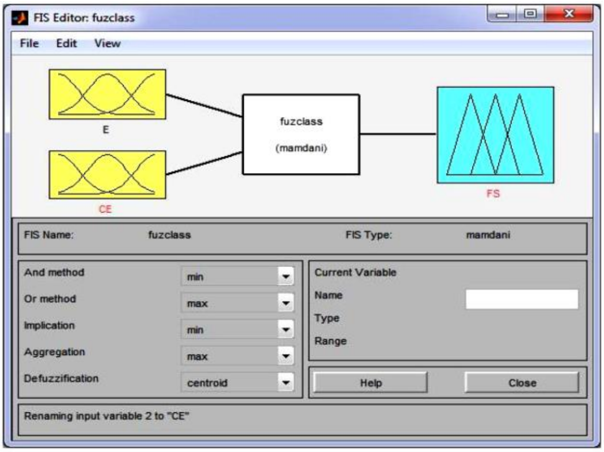

Fig. 5: Implemented Matlab/Simulink Fuzzy logic controller

From figure 6, we can see that both algorithm track accurately the maximum available power with best performances and less steady state oscillations for the proposed fuzzy-PO MPPT controller.

The figure 7 below shows the duty cycle provided by both conventional P&O (fixed step size) and proposed indirect hybrid fuzzy-PO algorithms (variable step size), respectively.

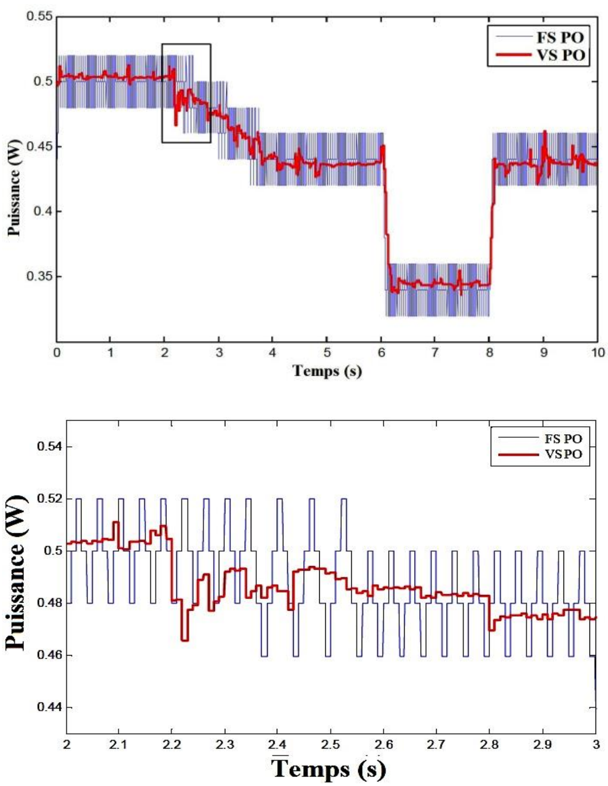

Fig. 7: DC/DC PWM duty cycle

Figures 8 to 11 present the detailled zoomed parts for both algorithm in case of insolation variations: 1000 W/m^2 (**Point A**),

Soft linear variation (**Point B**) to 800 W/m^2 (**Point C**), and fast variation from 00 W/m^2 to 800 W/m^2 (**Point D**).

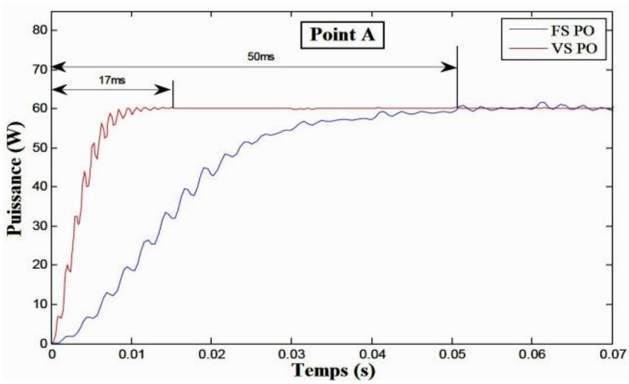

Fig. 8: **Point A**: Convergence Speed in case of startup

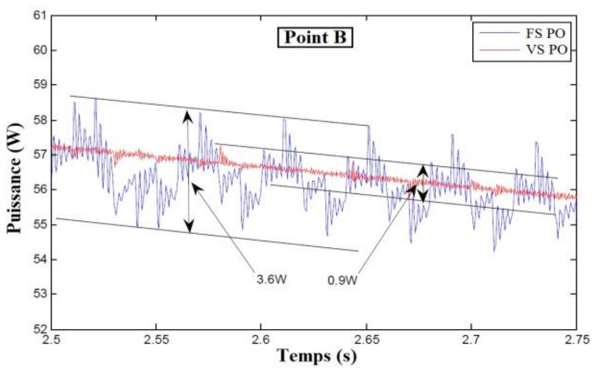

Fig. 9: **Point B**: Oscillation in case of soft changing atmospheric conditions

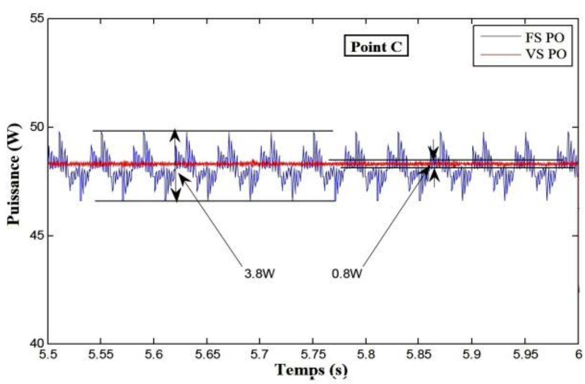

Fig. 10. **Point C**: Steady state oscillation i,
case of fast changing atmospheric conditions.

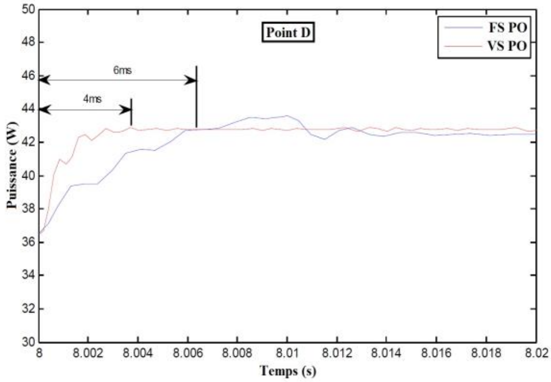

Fig. 11: **Point D**: Convergence speed in case of fast changing atmospheric conditions

From figures 8 to 11, we can see that the proposed indirect hybrid fuzzy-PO MPPT controller outperforms the conventional fixed step size PO MPPT controller in all cases showing an improvement of MPPT performances in dynamic increasing the convergence speed by the reduction of the response time (**Points A** and **D**) as well as the reduction of the steady state oscillation around the MPP point (**Point B** and **point C**) which will reduce effectively improve the amount of energy transferred to the load.

4. CONCLUSION

In this paper, an indirect hybrid fuzzy-PO variable step size MPPT controller has been proposed for PV systems. The fuzzy logic controller is used to scale the variable step size of the conventional PO MPPT controller needed by the PWM duty cycle generator to drive DC/DC boost converter.

The proposed MPPT controller improve the dynamic as well the static performances of the classical P&O algorithm by scaling the step size to have a tradeoff between algorithm convergence speed and steady state oscillations around the MPP point especially in case of rapidly changing insolation levels.

The simulation results done using Matlab/Simulink environment prove the effectiveness of the proposed MPPT controller to improve performances in all tested cases.

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