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IMPROVEMENT OF THE PERFORMANCE OF THE MAXIMUM POWER POINT TRACKING METHOD USING FUZZY LOGIC

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Abstract

The conventional MPPT techniques face challenges in accurately tracking the maximum power point (MPP) under varying environmental conditions and load characteristics. This research proposes an enhancement to the MPPT method by incorporating fuzzy logic control, aiming to improve the overall performance and robustness of the system [1]. By employing fuzzy logic in the MPPT algorithm, the system can effectively handle the uncertainties and non-linearities associated with PV systems. The proposed method takes advantage of the fuzzy logic controller to adjust the operating conditions of the PV system, optimizing the power extraction process and achieving better performance. The research involves the development of a fuzzy logic-based MPPT algorithm, where the input parameters such as solar irradiance, temperature, and voltage are fuzzified to linguistic variables. The fuzzy rules define the relationship between these variables, guiding the control actions. The algorithm continuously updates and adjusts the duty cycle of the power converter to ensure that the PV system operates at its MPP.

Keywords: FLC: Fuzzy Logic Controller**,** P&O: Perturb and Observer**,** PV: Photovoltaic**,** MPPT: Maximum Power Point Tracking

1. INTRODUCTION

Photovoltaic (PV) systems have gained a lot of attention in recent years due to the increasing demand for clean and renewable energy sources. PV panels are widely used in various applications such as residential, commercial, and industrial sectors. The performance of the PV system depends on various factors such as the efficiency of the PV panel, environmental conditions, and the maximum power point tracking (MPPT) method used[1].

The MPPT method is used to extract the maximum power from the PV panel by continuously adjusting the operating point of the panel. The conventional MPPT methods, such as perturb and observe (P&O) and incremental conductance (IncCond), are widely used due to their simplicity and ease of implementation. However, these methods have some limitations such as oscillations around the maximum power point (MPP) and slow convergence under rapidly changing irradiation conditions[2].

To overcome these limitations, various advanced MPPT methods have been proposed in the literature, such as fuzzy logic control (FLC), artificial neural network (ANN), and genetic algorithm (GA). [3]Among these methods, FLC has gained significant attention due to its ability to handle nonlinearities and uncertainties in the system.

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In this paper, we propose the use of fuzzy logic to improve the performance of the MPPT method. A fuzzy logic controller (FLC) is designed to adjust the duty cycle of the dc-dc converter to track the MPP with high accuracy and fast response[4]. The proposed FLC-based MPPT method is compared with the conventional P&O and IncCond methods under different irradiation conditions using MATLAB/Simulink simulation. The simulation results demonstrate that the proposed method has superior performance in terms of tracking accuracy, convergence speed, and robustness.

The rest of the paper is organized as follows. Section 2 provides a brief review of the MPPT methods. Section 3 presents the proposed FLC-based MPPT method. Section 4 presents the simulation results and discussions. Finally, the conclusions are drawn in Section .

2. DESCRIPTION OF THE MPPT CONTROL SYSTEM

A photovoltaic (PV) system consists of a PV panel (Fig 1), a DC-DC converter, and a load. The PV panel converts the solar energy into electrical energy, and the DC-DC converter is used to adjust the voltage and current levels of the PV panel to match the load requirements. The maximum power point tracking (MPPT) method is used to extract the maximum power from the PV panel by continuously adjusting the operating point of the panel.

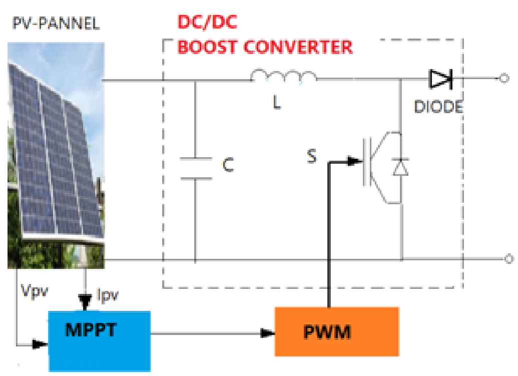

Figure 1: PV Conversion Chain With MPPT Control

The MPPT system works by measuring the voltage and current of the PV panel and calculating the power at each operating point. The maximum power point (MPP) is the point on the voltage-current (V-I) curve of the PV panel at which the power output is maximum. The MPPT system adjusts the operating point of the PV panel by varying the duty cycle of the DC-DC converter to track the MPP.

There are several MPPT methods that have been proposed in the literature, including the perturb and observe (P&O) method, the incremental conductance (IncCond) method, and the fuzzy logic control (FLC) method. The P&O method works by perturbing the operating point of the PV panel and observing the change in power output. If the power output increases, the operating point is moved in that direction, and if it decreases, the operating point is moved in the opposite direction. The IncCond

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method calculates the incremental conductance of the PV panel and adjusts the operating point to match the MPP. The FLC method uses a fuzzy logic controller to adjust the duty cycle of the DC-DC converter to track the MPP with high accuracy and fast response.

The choice of MPPT method depends on various factors such as the complexity of the system, the performance requirements, and the cost. The MPPT system plays a crucial role in improving the efficiency and performance of the PV system by extracting the maximum power from the PV panel under varying environmental conditions.

2.1. Perturb and Observe Method (P&O)

The Perturb and Observe (P&O) method is a technique used in maximum power point tracking (MPPT) algorithms for photovoltaic (PV) systems. [5]The goal of MPPT is to adjust the operating point of the PV system to the maximum power point (MPP) on the PV panel's I-V (current-voltage) curve to maximize the power output.

The P&O method works by continuously perturbing (adjusting) the operating point of the PV system and observing the effect on the power output. The perturbation can be a change in the duty cycle of a DC-DC converter or a change in the voltage or current set-point of the system. The change is usually small so that the system doesn't overshoot the MPP[6].

The algorithm compares the power output of the new operating point with the previous one (Fig 2). If the power output increases, the perturbation direction is maintained, and if the power output decreases, the perturbation direction is reversed. This process continues until the MPP is reached.

One of the limitations of the P&O method is its slow convergence speed, especially in rapidly changing weather conditions. In addition, it can cause oscillations around the MPP, which can result in reduced efficiency and instability in the system. Therefore, some modifications have been proposed to improve the performance of the P&O method, such as using a variable step size or introducing a hysteresis band to avoid oscillations.

The disadvantage of the P&O technique is that, at steady state (equilibrium), the operating point oscillates around the MPP, causing the loss of a certain amount of available energy. In addition to this, in the case of a sudden increase in irradiation, the P&O algorithm reacts as if the increase is due to the effect of the previous perturbation, so it continues in the same direction, which is a wrong direction, causing it to move away from the true maximum power point [7].

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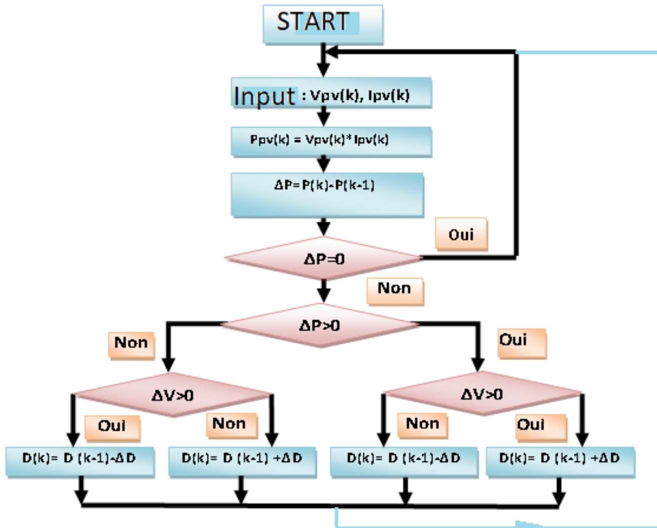

Figure 2: P&O Technique Algorithm

3. FUZZY LOGIC METHOD

The Fuzzy Logic Method (FLM) is another technique used in maximum power point tracking (MPPT) algorithms for photovoltaic (PV) systems. FLM is a rule-based system that uses linguistic variables to control the operation of the PV system[8].

The FLM-based MPPT algorithm is designed based on a set of rules that describe the behavior of the system. These rules are written using linguistic terms, such as "high," "medium," and "low," to describe the input and output variables of the system. The input variables are usually the PV panel voltage and current, while the output variable is the duty cycle of the DC-DC converter.

The FLM-based MPPT algorithm uses a set of membership functions to map the input variables to the fuzzy linguistic terms. These membership functions define the degree of membership of each input variable to each linguistic term. The algorithm then applies a set of fuzzy rules to determine the output variable (duty cycle of the DC-DC converter).

The output variable is also mapped to a set of linguistic terms using membership functions. These membership functions define the degree of membership of the output variable to each linguistic term.

The output variable is then defuzzified to obtain a crisp value of the duty cycle, which is used to control the operation of the DC-DC converter. The advantage of the FLM-based MPPT algorithm is its ability to handle imprecise and uncertain information, such as changing weather conditions. FLM can also handle non-linear and complex systems and can provide good performance under different operating conditions. However, the design of FLM-based MPPT algorithms can be more complex than other MPPT techniques, and tuning the membership functions and fuzzy rules requires expertise and experience. Can be done in three steps: fuzzification, inference, and defuzzification. As shown in Figure 3. [9].

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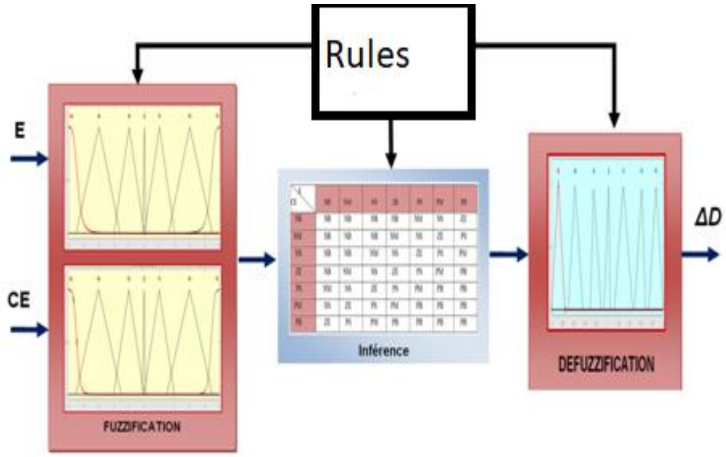

Figure 3: The Fuzzy Logic Method -Based MPPT Algorithm

Fuzzification : This step involves the method of converting numerical inputs into linguistic variables. The input variables to an MPPT fuzzy controller are the error E and the change in error, while the output of the fuzzy logic is the variation in the duty cycle ΔD of the DC-DC converter. E and CE can be respectively expressed by :

$$E(K) = \frac{P_{pv}(K) - P_{pv}(K-1)}{V_{pv}(K) - V_{pv}(K-1)} \quad (1)$$

$$CE(K) = E(K) - E(K-1) \quad (2)$$

Where Ppv and Vpv are respectively the power and voltage of the PV system.

Seven fuzzy sets are adopted for the input and output variables: PB: ‘Positive Big’, PM: ‘Positive Medium’, PS: ‘Positive Small’, ZE: ‘Zero Equal’, NS: ‘Negative Small’, NM: ‘Negative Medium’, NB: ‘Negative Big’ [10].

Figure 4: shows the chosen membership functions for the input and output variables

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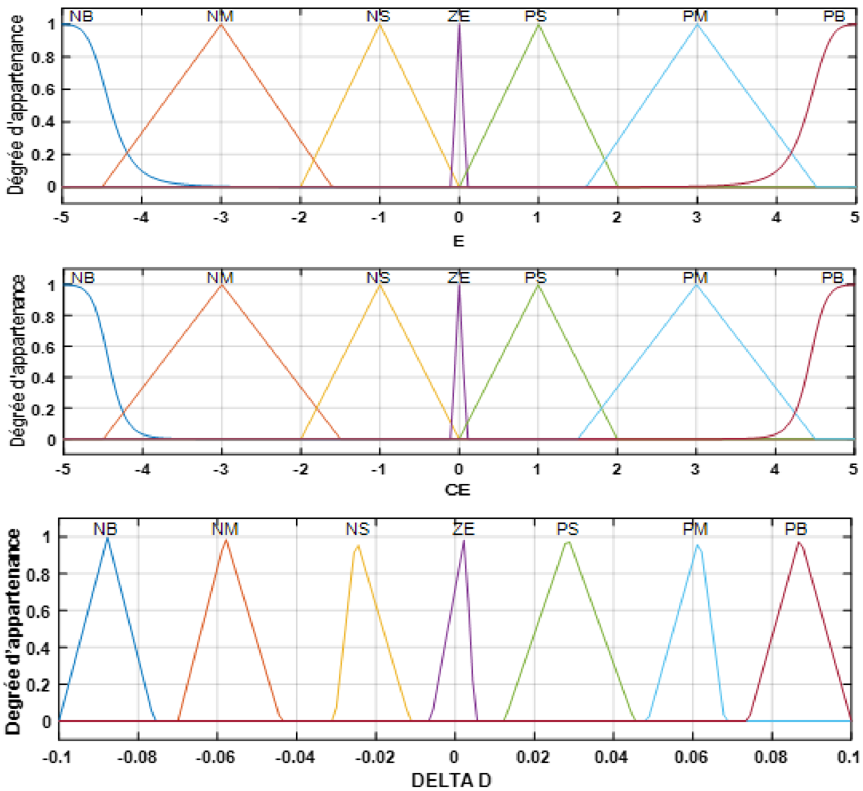

Figure 4: Membership functions of the inputs: E, CE, and the output ΔD

3.1. Inference Method

The modeling consists in building a mathematical model, translating Mamdani method is used as a fuzzy inference method in the MPPT fuzzy controller. The inference matrix for the MPPT fuzzy controller is presented in Table 1. The control rules must be designated in such a way that the input variable (E) should always be equal to zero. The Mamdani method is chosen as the fuzzy inference method in this study. It consists of using the 'MIN' operator for 'AND' and the 'MAX' operator for 'OR' [11][12].

E \ CE	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Table 1: Fuzzy MPPT inference table

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3.2 Defuzzification

Defuzzification is the step that consists of going from the "fuzzy domain" to the "real domain". It can be approached with different methods, but the most popular one is called the "center of gravity" method. The center of gravity of the membership function μ(Di) is simply calculated to obtain the real values, it is given by:

$$\Delta D = \frac{\sum_{i=1}^{n} \mu(D_i) - D_i}{\sum_{i=1}^{n} \mu(D_i)} \quad \textbf{(3)}$$

The developed PV conversion chain consists of two main elements:

¬ A PV generator composed of eight modules connected in series and five modules connected in parallel to provide an output power of 8 kW. The PV module consists of 54 cells connected in series to offer a power of 200 W,

¬ A boost-type chopper controlled by an MPPT controller.

In order to evaluate the efficiency, stability, and performance of the two MPPT techniques: P&O and fuzzy logic, the PV system must be tested at a temperature of 25°C as shown in (fig 6), and under different irradiations, the illumination is rapidly decreased from 1000 to 400 W/m2 during the first second, then from 2 seconds, it is increased to the value of 900W/ m2, finally, it is gradually decreased to the value of 600W/m2 from the 3rd second, as indicated in (fig 5). The used parameters are summarized in the appendix.

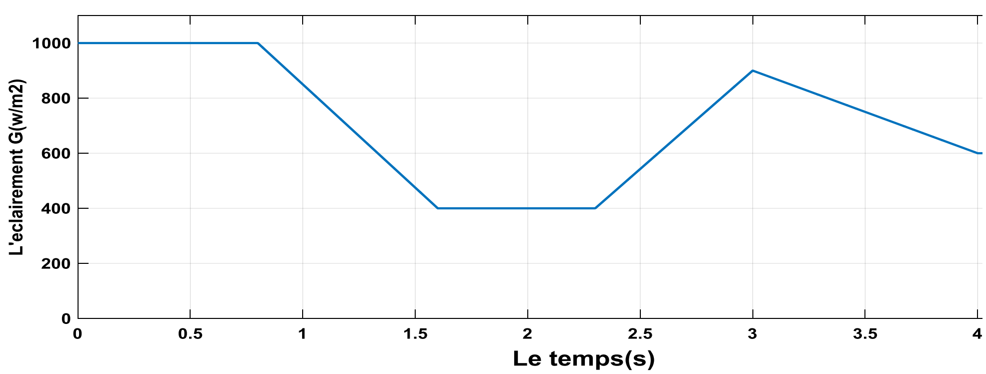

Figure 5: Irradiance profile

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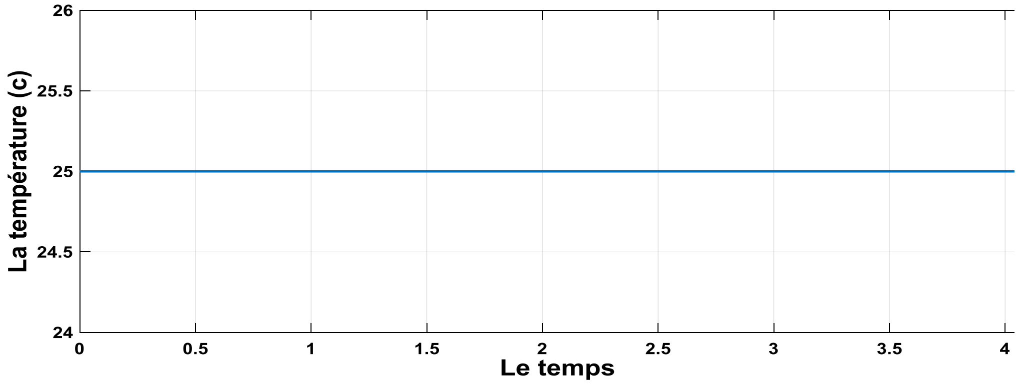

Figure 6: Temperature profile

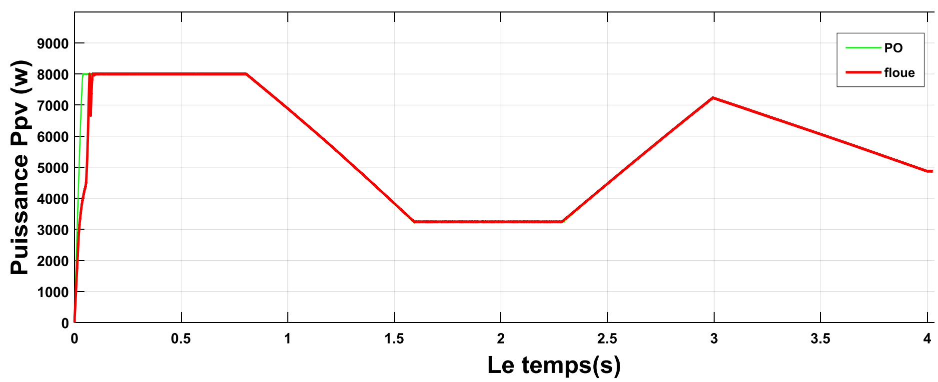

Figure 7: Output power of the PV system.

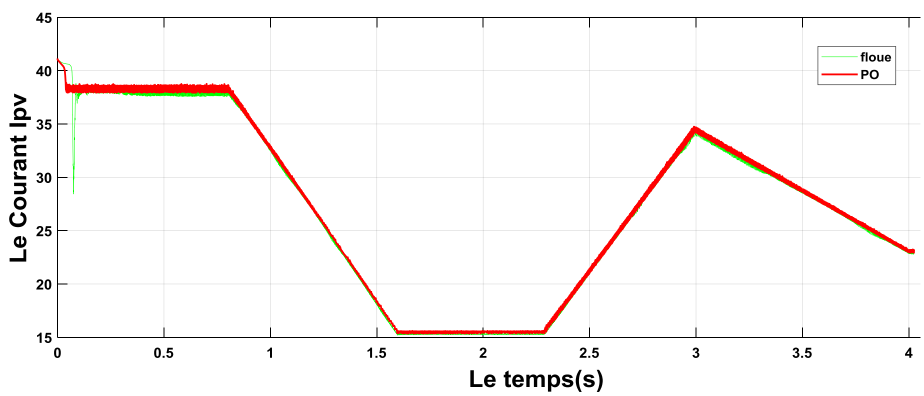

Figure 8: Courant du système PV

4. RESULTS AND INTERPRETATION

Maximum Power Point Tracking (MPPT) is a technique used to extract maximum power from photovoltaic (PV) modules. Fuzzy logic is a control system that uses fuzzy set theory to approximate complex systems. The use of fuzzy logic in MPPT has been proposed as a way to improve the performance of the technique.

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The application of fuzzy logic to MPPT involves using linguistic variables such as "small," "medium," and "large" to represent the output power of the PV module. These linguistic variables are used to define the rules for the control system, which determines the optimal operating point of the PV module. Fuzzy logic can adapt to changing weather conditions, such as clouds passing over the PV module, and adjust the operating point accordingly.

The simulation results show that the PV system produces maximum power regardless of the weather conditions with both P&O and fuzzy logic MPPT applied. However, it is observed that the P&O algorithm exhibits oscillations around the optimal value, and these oscillations around the MPP can be minimized by reducing the perturbation step size, D. However, dynamic performance is hindered by a smaller perturbation step size. The other technique, fuzzy logic, offers superior performance. It operates at the optimal point without oscillations. The performance of fuzzy logic-based MPPT has been compared to conventional MPPT methods, such as Perturb and Observe (P&O) and Incremental Conductance (IncCond), in various studies. The results have shown that fuzzy logic-based MPPT can achieve higher efficiency and faster tracking speed in some cases. However, the performance improvement depends on the design of the fuzzy logic controller and the specific environmental conditions.

One of the advantages of fuzzy logic-based MPPT is its ability to handle non-linear and complex systems. However, the design and tuning of the fuzzy logic controller can be time-consuming and requires a good understanding of the system dynamics. Additionally, fuzzy logic-based MPPT may require more computational resources than conventional MPPT methods, which can affect its implementation in low-cost PV systems.

5. CONCLUSION

In conclusion, the application of fuzzy logic to maximum power point tracking (MPPT) algorithms has shown to be a promising approach to improving the performance of photovoltaic (PV) systems. The Fuzzy Logic Method (FLM) is a rule-based system that can handle imprecise and uncertain information, making it suitable for MPPT in changing weather conditions. Compared to traditional MPPT techniques, FLM-based MPPT algorithms can provide better performance under different operating conditions, especially when the PV panel is subject to partial shading or non-uniform irradiance. FLM can also handle non-linear and complex systems, which is important in real-world PV systems. However, the design of FLM-based MPPT algorithms can be more complex than other MPPT techniques, and the tuning of the membership functions and fuzzy rules requires expertise and experience. Therefore, further research is needed to optimize the design and implementation of FLM-based MPPT algorithms for practical applications.

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APPENDIX

Component parameters of the SHE. PV panel (KC200GT) under standard conditions (Gn = 1000 W/m2 and Tn = 25°C).

Maximum power	Pmax	200 W
Open circuit voltage	Voc	32.9 V
Short circuit current	Isc	8.21 A
Saturation current of the diode	Isat	9.8214.10-8 A
Photo-current	Iph	8.214 A
Series resistance	Rs	0.221 Ω
Parallel resistance	Rp	415.405 Ω
Ideality factor of the diode	α	1.3
Number of PV cells connected in series	Ns	54

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