Fuzzy MPPT Control of Photovoltaic Energy System

Walaa Mohammed, Elkhatib Kamal, Abdul Azim Sobaih

Abstract—This paper displays an exhaustive comparison of the Perturb-and-Observe (P&O) and Mamdani fuzzy implementation methods for achieving high performance, stability of the system and energy usage of Photovoltaic energy (PV) systems. Comparison with the present approaches, larger stability can be recorded. PV has been showing the presented fuzzy controllers robustness and stability property. For verifying the execution of the proposed controller, we make comparison with P&O method and we can confirm that controller can track the maximum power point. The performance of the proposed controller design methodology is finally proved by photovoltaic array to maximize the Photovoltaic (PV) system.

Index Terms— Perturb-and-Observe, Mamdani Fuzzy, Fuzzy Control System, the PV Power.

I. INTRODUCTION

The universe is certificating squeezes of energy and pollution of environment in a high degree. To solve these consequences assurance is being going to renewable energy. Photovoltaic energy (PV) takes part a pivotal grade in green (renewable) energies sources; cause why its use has been a great spread [1]. However of this, a PV generator has two worthy consequences; 1) The load must match PV conductance of the PV generator to ensure the maximum power transfer [1], [2]. 2) The PV system is non-linear and it is faces external disturbances like temperature and solar irradiation [3]. Actually the fuzzy control has been outspreaded to transact with the uncertain nonlinear systems. Since parameter uncertainties are frequently one of the causes of system instability and system retraction of execution[4], different robust stability and stabilization methodologies have been proposed [5]-[8]. Sufficient stability conditions were derived by using the Lyapunov's method [9], [10]. Fuzzy controllers using linear state feedback controllers as sub-controllers were also stated. The fuzzy sliding mode controller behaves like a conventional sliding mode controller with a boundary layer about the sliding plane [11]. In [12]-[14] the fuzzy controller design was reported. The difficulty in using the continuous-time with fuzzy Lyapunov function consists in the following: 1) the time derivatives of the fuzzy basis functions appear, which increments the hardness of the stability analysis, and 2) sufficient conditions approved using the fuzzy Lyapunov function. In addition, tracking the maximum power point (MPP) of a photovoltaic module/array is an important task in a PV control system, to maximize the PV module's efficiency [15].

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However, the MPP locus varies over a wide range, depending on varying temperature and radiation intensity. Thus, an maximum power point tracking (MPPT) can reduce the overall system cost. Many techniques have been presented [16]-[18], like Perturb-and-Observe (P&O) which is the most commonly used. However, P&O has some restriction like it fails under high changing environment conditions. On the other hand, speed and accuracy are considered as the principle parameters depend on some other methods like Mamdani fuzzy logic and classical stability analysis methods for fuzzy systems have been presented [19]-[22], but fuzzy logic controller methods need stability and performance analysis. To achieve the MPPT under strict theoretical analysis, the fuzzy control is applied. In this paper, we have compared P&O method and Mamdani fuzzy logic controller. Indeed, the proposed algorithm based on the work presented in [13], [14]. The time boundary derivative of the fuzzy basis functions and the membership functions is not required and higher stability regions. Comparison with other works on robust control like the fuzzy sliding mode control technique [11], our approach is easier and simpler, and the construction is simple. In addition, the maximum power problem is presented. The effectiveness of the proposed controller design methodology is finally demonstrated through PV system to illustrate the effectiveness of the proposed method. Comparing to the pervious algorithms [13], [14], the proposed control scheme can guarantee the stability of the closed-loop system and the convergence of the output tracking error. This paper is organized as follows. In section II, we introduce the solar power generation system model. The proposed robust controller is presented in section III. Simulation is concluded in section IV. Finally, section V states the conclusions.

II. PV SYSTEM MODEL

In order to adapt the array photovoltaic to a large voltage range, the PV MPPT system adopts Buck-Boost DC-DC converter topology as shown in Fig.1 [23]-[25]. When the buck-boost converter is used in PV applications the input voltage changes continuously with the atmospheric conditions. Therefore, the duty cycle should change to track the maximum power point of photovoltaic array. To show the effectiveness of the proposed controller design techniques, PV Model System [18]-[20] are simulated. The state equation and output equation can be expressed by the following [23]-[25]:

$$\dot{x}(t) = A(x)x(t) + B(x)u$$
$$y(t) = Cx(t) \qquad (1)$$

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where

$$x(t)=\begin{bmatrix} v_{pv} \\ i_L \\ v_o \end{bmatrix},\ A(x)=\begin{bmatrix} \frac{i_{pv}}{C_1 v_{pv}} & 0 & 0 \\ 0 & 0 & -\frac{1}{L} \\ 0 & \frac{1}{C} & -\frac{1}{CR} \end{bmatrix},\ B(x)=\begin{bmatrix} 0 & \frac{i_L}{C} & 0 \\ \frac{v_{pv}}{L} & 0 & \frac{v_o}{L} \\ 0 & -\frac{i_L}{C} & 0 \end{bmatrix},$$

$$C^T=\begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \end{bmatrix}$$

Where i_L is the current across the inductor L, v_0 is the voltage in the capacitor C, u is the duty ratio of the Pulse-Width-Modulated (PWM) signal to control the switching MOSFET, $u \in \{0,1\}$ defines the switch position and supposed that the parameters R, L, C_1 and C are supposed to be known constants.

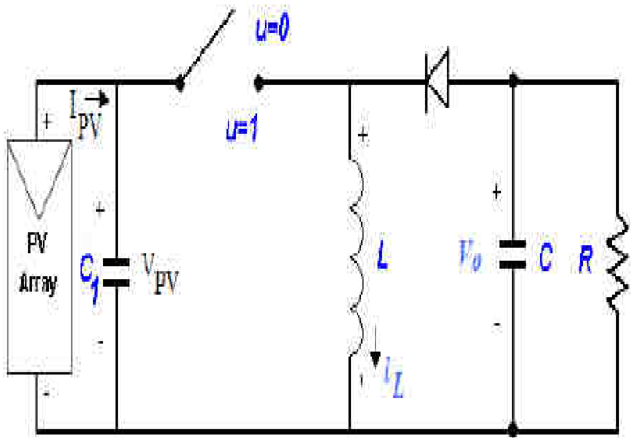

Fig. 1. PV power control system using a Buck-Boost DC-DC converter

III. THE PROPOSED ROBUST CONTROLLER

In this section, we will present the proposed control strategy as the following subsections. The control strategy consists of MPPT strategy and the proposed fuzzy controller.

A. MPPT algorithm

The power generation of the PV array [26] is given by:

$$P_{pv}=i_{pv}v_{pv}=n_p I_{ph} v_{pv}-n_p I_{rs} v_{pv}(\exp(q v_{pv}/n_s \varphi KT)-1) \quad (2)$$

where n_p and n_s are the number of the parallel and series cells, respectively, K is the Boltzmanns' constant, T is the cell temperature, φ is the p-n junction characteristic, q is the electron charge, i_{pv} and v_{pv} are the output current and the PV array voltage on the capacitance C_1, I_{ph} and I_{rs} are the photocurrent and reverse saturation current, respectively and are given by

$$I_{ph}=(I_{sc}+K_I(T-Tr))\frac{\lambda}{100} \quad (3)$$

$$I_{rs}=I_{or}\left(\frac{T}{T_r}\right)^3 \exp(qE_{gp}(1/T_r-1/T)/K\varphi) \quad (4)$$

where I_{sc} is the short-circuit cell current at reference temperature and insolation, I_{or} is the reverse saturation current at the reference temperature T_r, E_{gp} is the semiconductor band-gap energy, K_I is the short-circuit current temperature coefficient and λ is the insolation in mW/cm^2. According to the electric power equation (2), the PV power slope dP_{pv}/dv_{pv} can be expressed as follows:

$$\frac{dP_{pv}}{dv_{pv}}=i_{pv}+v_{pv}\frac{di_{pv}}{dv_{pv}}$$

$$=i_{pv}-n_p I_{rs} v_{pv}(q/n_s\varphi KT)(\exp(q v_{pv}/n_s\varphi KT) \quad (5)$$

Therefore, when the power slope dP_{pv}/dv_{pv}=0, the system operates at the maximum power generation ($P_{pv(max)}$) this point corresponding the PV maximum current ($i_{pv(max)}$) and PV maximum voltage ($v_{pv(max)}$). The incremental conductance algorithm is based on the differentiation of PV power to its voltage and on condition of zero slope of P-V curve in MPP [2], [26]. Based on the P-V characteristic curve, the MPPT algorithm can be given [26] as the following:

if $\frac{di_{pv}}{dv_{pv}}>-\frac{i_{pv}}{v_{pv}};\left(\frac{dP_{pv}}{dv_{pv}}>0\right)$, Left of MPP, then increase v_{pv}.

If $\frac{di_{pv}}{dv_{pv}}=-\frac{i_{pv}}{v_{pv}};\left(\frac{dP_{pv}}{dv_{pv}}=0\right)$ at MPP, then v_{pv} must remain constant. if $\frac{di_{pv}}{dv_{pv}}<-\frac{i_{pv}}{v_{pv}};\left(\frac{dP_{pv}}{dv_{pv}}<0\right)$,Right of MPP, then decrease v_{pv}. The basic relation between the input (v_{pv}) and output (v_o) voltage of this converter is given by,

$$\frac{v_o}{v_{pv}}=\frac{d}{1-d} \quad (6)$$

By using duty cycle d, there is a linear relationship between the two voltages. So, in the algorithm implementation, it is essential to control and change d. The reference voltage is determined from the incremental conductance method [2], [6]. Fig.2 shows a flowchart of the proposed strategy.

B. Perturbe & Observe (P&O) MPPT Technique

The Perturb and Observe method is considered as the most algorithms used in practice by the majority of authors to track the maximum power point [16]-[18] among others. Its principle is based on the perturbation of the system by the increase/decrease of the duty-cycle of the converter and the observation of the effect on the output power [16]-[18]. If a given perturbation leads to an increase (decrease) in the output power of the PV, then the subsequent perturbation is generated in the same (opposite) direction, otherwise the perturbation is inverted. The duty cycle is varied and the process is repeated until the maximum power point has been reached, that leads the system to oscillate about the MPP. In Fig.2, it is given a flowchart which describes the P &O technique.

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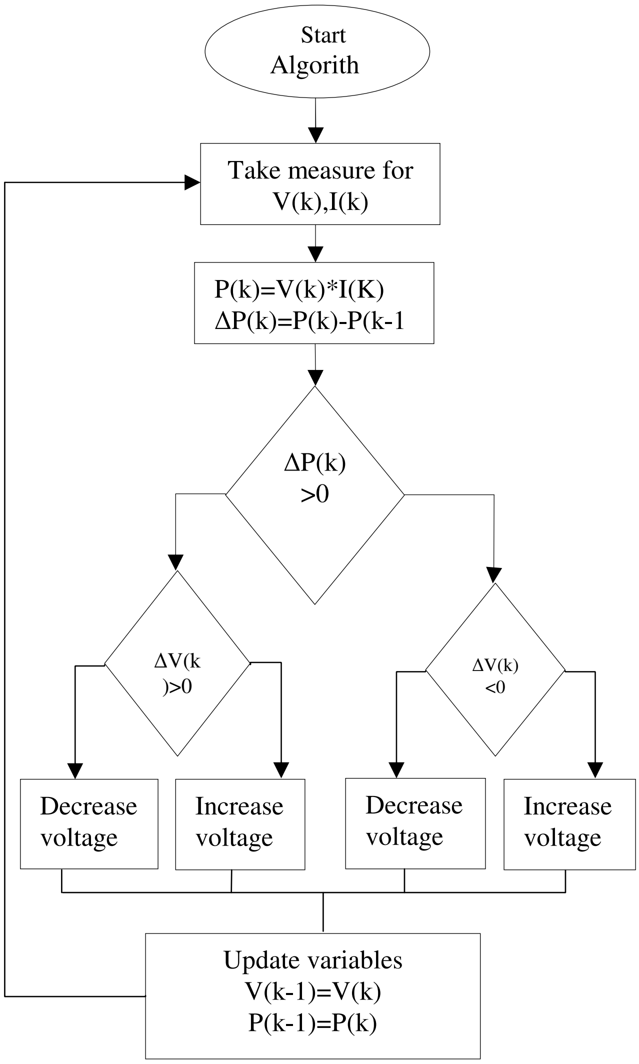

Fig. 2. Flowchart of the perturb & observe method

C. Mamdani Fuzzy Inference Method

Fuzzy logic controllers (FLC) are presented in tracking of the MPP [19]-[22].The fuzzy controller has four components.(i) the"rule-base" needs the knowledge, collection of rules, of how best to control the system; Table 1, it is showed the different fuzzy rules used in Mamdani fuzzy controller to track the maximum power point.(ii) The inference mechanism modifies which control rules are much related at the present time and then makes decision which input to the plant must be.(iii) The fuzzification interface simply adjustments the inputs for interpreting and comparing to the rules in the rule-base, inputs are expressed as linguistic variables denoted NB(Negative Big),NS(Negative Small),Z(Zero),PS(Positive Small),PB(Positive Big).the fuzzification of the input variables by triangular MFs.(iv) the defuzzification interface converts the conclusions reached by the inference mechanism into the inputs to the plant (crisp value)[19]. defuzzication of the rules in order to obtain the crisp values of the duty cycle perturbations. The input variables and the control action for tracking of the maximum power point are illustrated in Fig.3 to Fig.5.

Table.1-FLC Rules Base

DV \ DP	NB	NS	Z	PS	PB
NB	NS	NB	NB	PB	PS
NS	Z	NS	NS	PS	Z
Z	Z	Z	Z	Z	Z
PS	Z	PS	PS	NS	Z
PB	PS	PB	PB	NB	NS

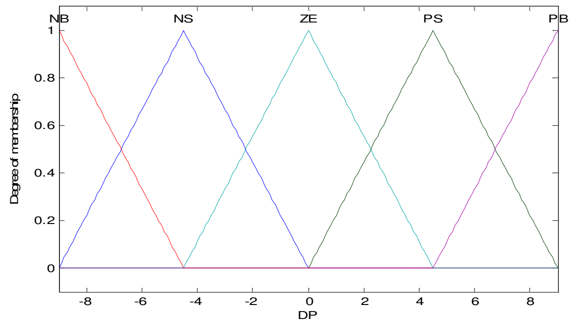

Fig. 3. Membership functions for the Power change

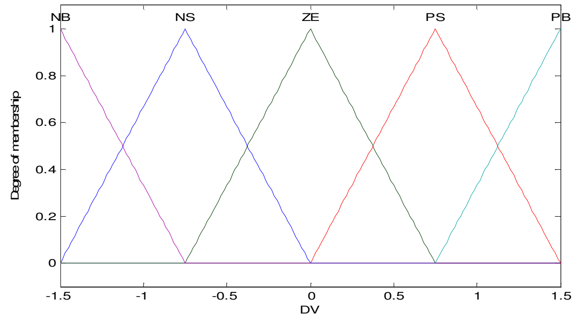

Fig. 4. Membership functions for the change of PV voltage

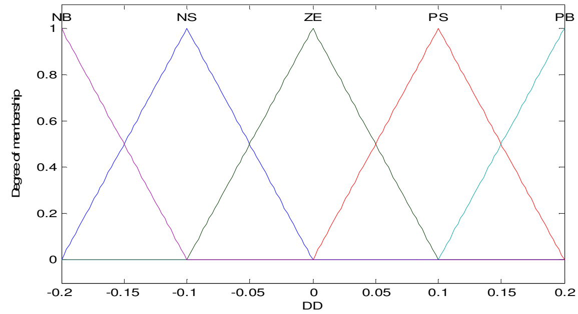

Fig. 5. Membership functions for the duty cycle u

IV. SIMULATION AND RESULTS

Simulations were performed in MATLAB/Simulink using the nonlinear model provided in section II. To illustrate the effectiveness of the proposed method, we compare the results of the two algorithms P&O, Mamdani fuzzy logic control. Consider varying temperature *T* and varying insolation shown in Fig.6 and Fig.7, respectively. The PV voltage, current and power for the P&O [16] (dotted line), [17], Mamdani fuzzy logic control [19]-[22] (dashed line) are shown in Figs. 8, 9 and 10, respectively. From the ssimulations, Figs. 8, 9and 10

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it can be seen that for strategy, the PV power quickly achieves to the maximum value.

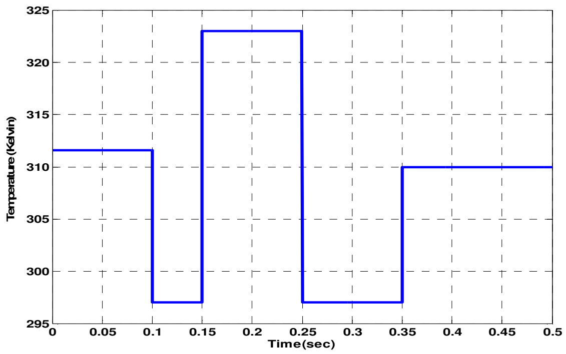

Fig. 6: Temperature profile

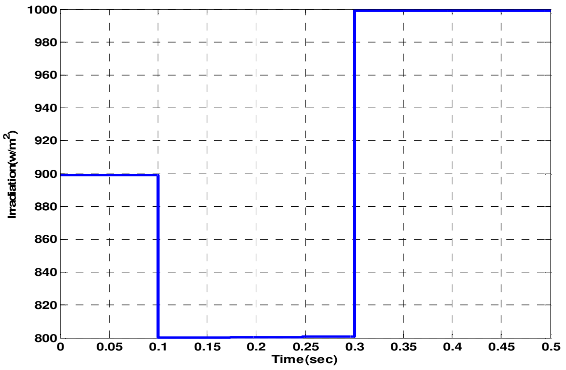

Fig. 7: Insolation profile

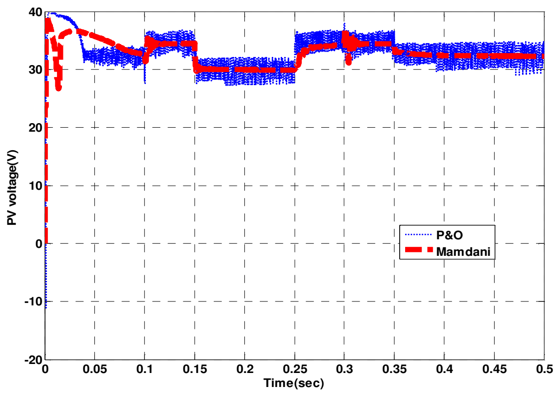

Fig. 8: Response of the PV voltage for the P&O (dotted line), Mamdani fuzzy logic control (dashed line)

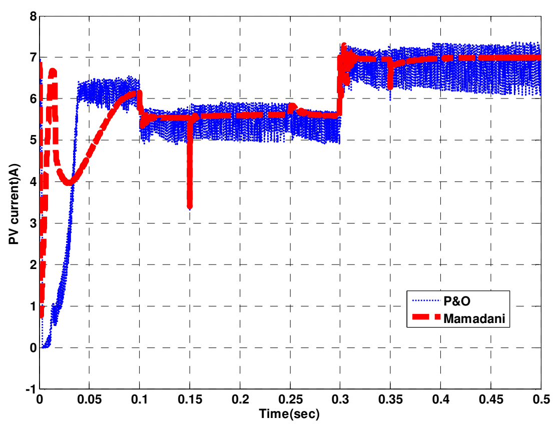

Fig. 9: Response of the PV current for the P&O (dotted line), Mamdani fuzzy logic control (dashed line)

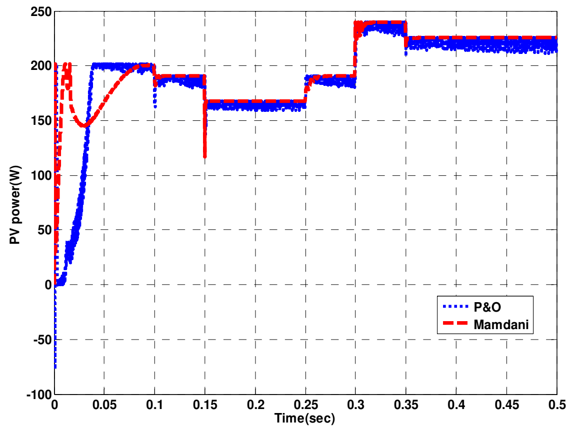

Fig. 10: Response of the PV power for the P&O (dotted line), Mamdani fuzzy logic control (dashed line)

From the simulation, it can be seen that the performance of the system under the control of the P&O (dotted line), Mamdani fuzzy logic control (dashed line) provides a good tracking comparing to the other algorithms. In summary, a fuzzy controller has been proposed to tackle this nonlinear system. The stabilizing PV system has been given to illustrate the design procedure and merits of the proposed fuzzy controller. This algorithm of fuzzy controller has advantages over the previous algorithm, in terms of a lower demand on computational power and a simpler controller structure.

V.CONCLUSION

The Mamadani fuzzy method based stability and robustness conditions of a PV system. The resulting fuzzy controller is capable of tackling multivariable nonlinear systems subject to large parameter uncertainties. Larger stability regions can be guaranteed. PV has been given to illustrate the stabilization and robustness property of the proposed fuzzy controllers. The implementation of the proposed controller in a PV showed that the system is kept stable over a wide range of uncertainties up to 35%. In possible the strategy MPPT of fuzzy logic controller (FLC) is well be implemented on a dsPIC.

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