

# **Adaptive Fuzzy Proportional Integral Derivative Controller Based Maximum Power Point Tracking For Photovoltaic System**

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**ABSTRACT:**Due to nonlinear P-V characteristics of photovoltaic generator, a maximum power point tracking(MPPT) algorithm is needed to optimize the performance of photovoltaic (PV) system. In this paper, an adaptive fuzzy proportional integral derivative (AFPID) control based maximum power point tracking strategy for photovoltaic system is proposed. The proposed adaptive fuzzy PID method integrates two level control system architecture, which combines the advantages of conventional PID and fuzzy logic control. Simulation results show that the designed controller guarantees convergence to the maximum power point under different climatic conditions and provides robust responses in rapid variation of load. Compared with the conventional perturb and observe (P&O) approach the proposed AFPID controller can simultaneously improve the dynamic and steady state performance of the PV system.

**KEYWORDS:**PV generator, MPPT, adaptive fuzzy PID controller, P&O, boost converter.

## **I. INTRODUCTION**

Among the available renewable sources, solar energy is one of the most important clean energy resources due to its environmental sustainability and inexhaustibility. Despite these advantages, the photovoltaic generation systems have two major drawbacks: the efficiency of solar energy conversion is low [1], and the electric power generated by photovoltaic modules changes with climatic conditions [2]. So to extract more PV energy a maximum power point tracking controller is needed to guarantee maximum power generation. Several MPPT strategies have been elaborated in the literature to achieve the maximum power point of PV system, starting with perturbation and observation (P&O) technique which is used widely due to its simplicity, however there is serious power oscillations around MPP which decreases the efficiency of PV system [3]. Other strategies based on artificial intelligence such as neural networks and genetic algorithms have developed. These methods suffer from oscillation of the operating point around the MPP which leading to significant energy losses especially in large scale photovoltaic systems [4]. In this paper an adaptive fuzzy proportional integral derivative control based maximum power point tracking strategy for photovoltaic system is proposed to maximize the power output of PV generator and to enhance the system performance. The designed controller combines advantages of conventional PID and fuzzy logic control. The gains of PID controller are tuned dynamically using a fuzzy logic controller the simulation results prove the effectiveness of the designed AFPID controller and demonstrate that this method can achieve a good maximum power operation under any conditions such as different intensities of solar irradiation and varying levels of load.

This paper is organized as follows: section II, gives a brief introduction of solar PV system modelling. Section III presents the P&O MPPT approach. The structure of the proposed adaptive fuzzy proportional integral derivative control based MPPT is detailed in section IV. Section V illustrates the obtained simulation results analysis and discussion. Finally, conclusions are given in section VI.

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## II. SYSTEM DESCRIPTION

Fig. 1 shows a synoptic scheme of the PV-stand-alone photovoltaic system used in this paper. It contains a photovoltaic generator of 135w, a dc-dc boost converter and a resistive load.

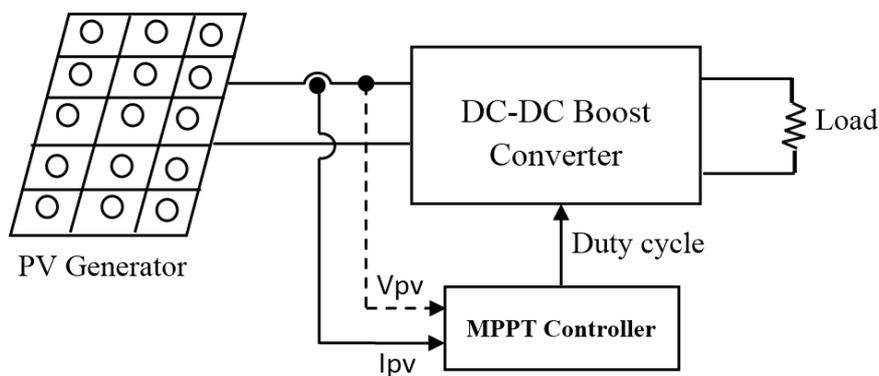


Fig. 1. Synoptic diagram of photovoltaic system [5]

### A. Photovoltaic panel model

A photovoltaic cell is a P-N semiconductor junction which converts solar irradiation into electric energy. Fig. 2 presents the equivalent circuit model of solar cell. This circuit includes a light generated source, diode, a series resistance  $R_s$  and a parallel resistance  $R_{sh}$ . The characteristic equation for a photovoltaic cell is given by (1).

$$I_{pv} = I_{ph} - I_0 \left[ \exp \left( \frac{q(V_{pv} + R_s I)}{nKT} \right) - 1 \right] - \frac{V_{pv} + R_s I}{R_{sh}} \quad (1)$$

Where  $I_{pv}$  and  $V_{pv}$  are the output current and voltage of photovoltaic cell,  $n$  is the ideality factor,  $k$  is the Boltzmann's constant,  $T$  is the cell's operating temperature in Kelvin,  $q$  is the electron charge,  $I_0$  is the reverse saturation current and  $I_{ph}$  is photo generated current. This last varies with temperature and solar insolation.  $I_{ph}$  is expressed by (2):

$$I_{ph} = [I_{sc} + K_1(T - T_r)] \frac{G}{1000} \quad (2)$$

Where  $T_r$  is the reference temperature,  $K_1$  is the cell's short-circuit current temperature coefficient,  $I_{sc}$  is the short circuit current at  $T_r$  and  $G$  is the irradiation in  $W/m^2$ .

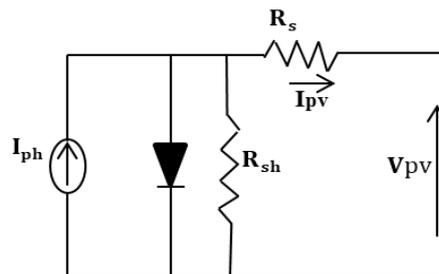


Fig. 2. PV cell equivalent circuit

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The reverse saturation current  $I_0$  depends on temperature  $T$  as follows:

$$I_0 = I_{rs} \left(\frac{T}{T_r}\right)^3 \exp \left[ \frac{qE_g}{nK} \left(\frac{1}{T_r} - \frac{1}{T}\right) \right] \quad (3)$$

Where  $I_{rs}$  is the saturation current at the reference temperature,  $E_g$  is the band gap energy of the semiconductor used in photovoltaic cell.

The parameters of the PV generator used in this work are depicted in table 1 and its P-V and I-V characteristics are shown in fig.3 and fig. 4 respectively.

Table 1: Electrical characteristics of the kyocera KD135GX-LP panel.

Parameter (at STC)	Value
Maximum power ( $P_{max}$ )	135.04 w
Voltage at $P_{max}$ ( $V_{mpp}$ )	17.7v
Current at $P_{max}$ ( $I_{mpp}$ )	7.62A
Open circuit voltage ( $V_{oc}$ )	22.09v
Short circuit current ( $I_{sc}$ )	8.36A
Temperature coefficient of $I_{sc}$ ( $K_i$ )	5.022mA/°c
Cell serial modules ( $n_s$ )	36

From Fig.3, we conclude that when the light intensity increases, the output power will increase. And from Fig. 4, it is observed that when the irradiation decreases, the output current decreases also but the open circuit voltage decreases slightly.

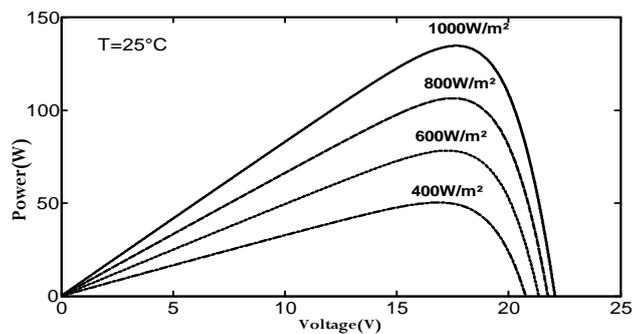


Fig. 3. P-V Characteristics of the photovoltaic panel at constant temperature  $T=25^\circ\text{C}$ .

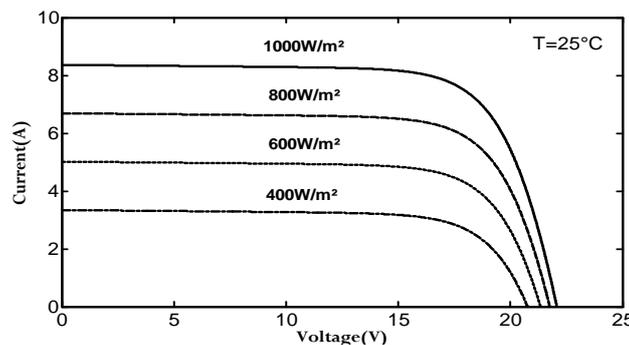


Fig. 4. I-V Characteristics of the photovoltaic panel at constant temperature  $T=25^\circ\text{C}$ .

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## B. DC-DC Boost converter

DC/DC powerconverters are most widely used in photovoltaic conversion systems as an intermediate between the PV generator and the load to operate thePV system at its MPP. In this study a boost converter is applied. As is depicted in fig. 5, this converter includes capacitor, inductor and electronic power switch. All of these components in the ideal case do not consume power; this is the reason why the choppers have good yields [6].The switch is turned ON and turned off by the PWM signal given by MPPT controller. The voltage gain of this converter can be expressed as:

$$\frac{V_{out}}{V_{in}} = \frac{1}{1 - d} \quad (4)$$

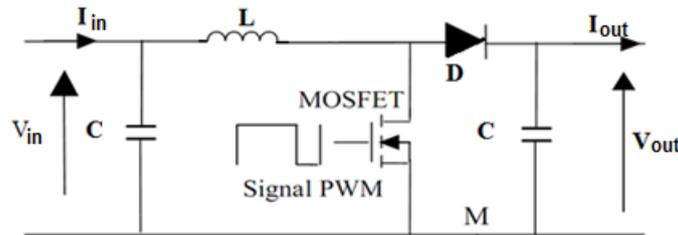


Fig. 5. Schematic circuit of DC-DC boost converter

## III. PERTURB AND OBSERVE MPPT APPROACH

Among all the MPPT strategies, the perturb and observe (P&O) method is widely employed in practice because of its ease of implementation and simplicity. The flowchart of the basic P&O MPPT technique is depicted in Fig.6. This method based on perturbs (increase or decrease) duty cycle and observe the output power of photovoltaic generator.If the output power is augmented due to the perturbation, this means that the operating point has moved toward the maximum power and, therefore, the following perturbation will be made in the same direction. But if the output power decreases, the new perturbation is made in the contrary direction. The major disadvantage of this technique is deviation from the maximum power point during rapidly changing climatic conditions.

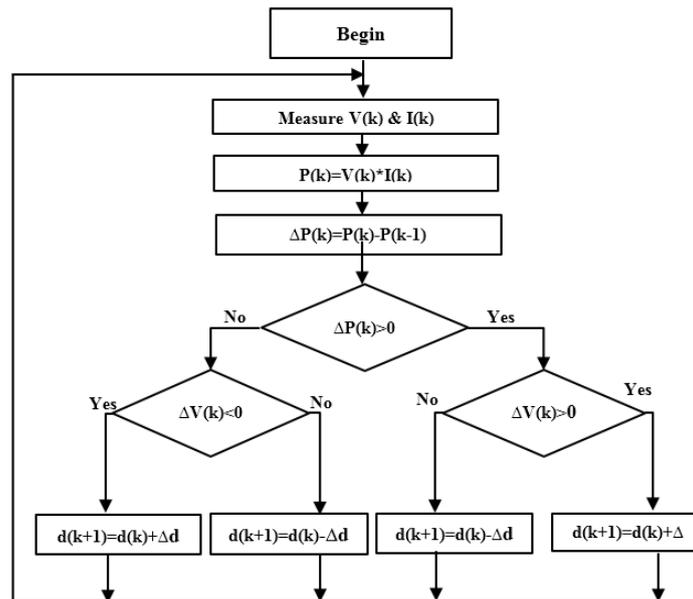


Fig.6. The flowchart of the algorithm P&O [10]

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## IV. PROPOSED ADAPTIVE FUZZY PID MPPT CONTROLLER

The designed adaptive fuzzy proportional integral derivative control based MPPT strategy includes two stages control which an online PID gain (proportional gain  $K_p$ , integral constant  $K_i$  and derivative constant  $K_d$ ) adjustment has been done using a fuzzy inference mechanism. The block diagram of the designed controller has been presented in fig. 7.

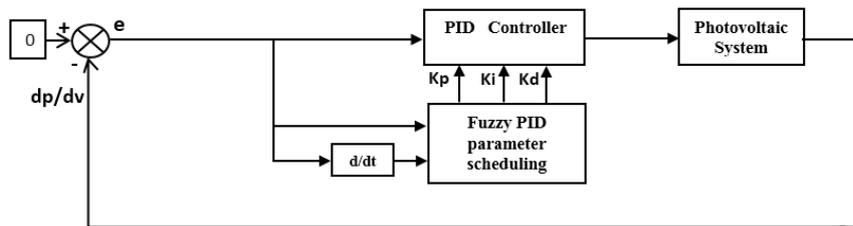


Fig. 7. Diagram of fuzzy adaptive PID controller

The conventional PID controller output is given by expression:

$$u(t) = K_p \left\{ e(t) + \frac{1}{T_i} \int_0^t e(\tau) d\tau + T_d \frac{de(t)}{dt} \right\} \quad (5)$$

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{de(t)}{dt} \quad (6)$$

Where  $e(t)$  is the error input,  $T_i$  is the integral time constant,  $T_d$  is the derivative time constant,  $K_p$  the proportional gain,  $K_i = K_p/T_i$  is the integral gain and  $K_d = K_p/T_d$  is the derivative gain [7]. It is well known that the P-V characteristics of PV generator change with climatic conditions which remain the traditional PID incapable to maintain the PV generator at its MPP. Therefore, the online adjustment of PID gains is needed for real MPPT [8]. So in this work a fuzzy inference mechanism is added to modify the parameters of the PID controller. The proposed fuzzy controller adopts two inputs and three outputs. Input variables are  $e$  and  $ec$ ; output variables are the proportional gain  $K_p$ , the integral gain  $K_i$ , the derivative gain  $K_d$ . The fuzzy subset of inputs and outputs linguistic variables are expressed as negative big (NB), negative small (NS), zero (Z), positive small (PS), positive big (PB). The fuzzy controller employs the triangle function, the Mamdani MaxMin fuzzy reasoning. The optimal values of the PID parameters can be obtained from the following equations:

$$K_p = K_{p \text{ initial}} + \Delta K_p \quad (7)$$

$$K_i = K_{i \text{ initial}} + \Delta K_i \quad (8)$$

$$K_d = K_{d \text{ initial}} + \Delta K_d \quad (9)$$

Where  $K_{p \text{ initial}}$ ,  $K_{i \text{ initial}}$  and  $K_{d \text{ initial}}$  are the initial values of the PID gains and  $\Delta K_p$ ,  $\Delta K_i$  and  $\Delta K_d$  are the values obtained by the fuzzy logic-based gain scheduling [9].

Table 2: Rules for proportional modification gain

Error(e)	Change of error(ce)				
	NB	NS	Z	PS	PB
NB	PB	PB	PB	PS	Z
NS	PB	PB	PS	Z	NS
Z	PB	PS	Z	NS	NB
PS	PS	PS	Z	NS	NB
PB	Z	NS	NB	NB	NB

Table 3: Rules for integral modification gain

Error(e)	Change of error(ce)				
	NB	NS	Z	PS	PB
NB	Z	Z	Z	NS	NS
NS	NS	NS	NS	Z	PS
Z	NB	NS	Z	PS	PB
PS	NS	NS	Z	PS	PS
PB	Z	Z	PS	Z	Z

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Table 4: Rules for derivative modification gain

Error(e)	Change of error(ce)				
	NB	NS	Z	PS	PB
NB	PS	NB	NB	NB	PS
NS	Z	NS	NS	NS	Z
Z	Z	NS	NS	NS	Z
PS	Z	Z	Z	Z	Z
PB	PB	PB	PS	PS	PB

## V. SIMULATION RESULTS

The whole system presented in fig. 1 has been simulated using Matlab/Simulink software. The system considered in this work consists of a 135w solar PV panel in which its specifications is stated in table1, DC-DC boost converter operating at switching frequency of 10 kHz. In order to prove the effectiveness of the proposed technique, the designed controller is employed to achieve MPP under varying irradiation conditions and load changing. A comparative study between the designed adaptive fuzzy PID controller and perturb and observe algorithm is performed. The developed Simulink block of the proposed controller is presented in fig. 8.

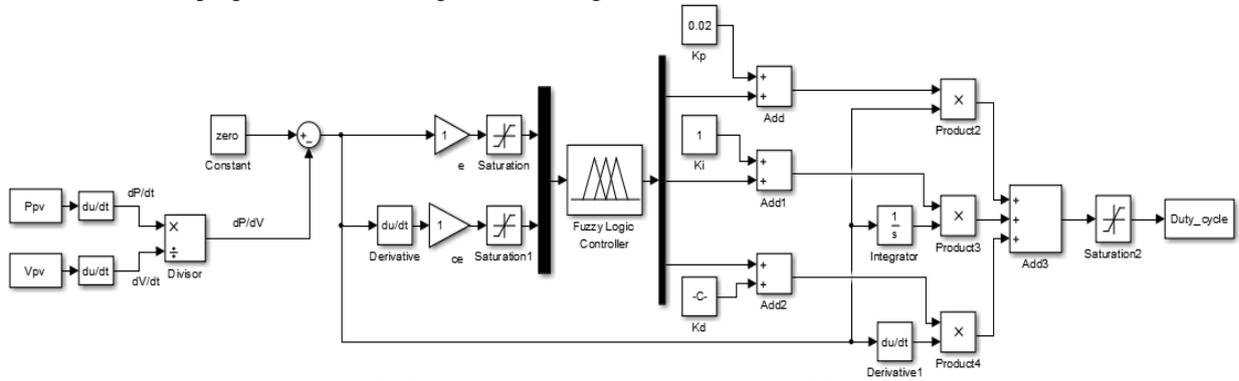


Fig. 8. The developed Simulink block of the proposed AFPID controller

The simulation is conducted to show the performance of the proposed technique. In the simulation, the solar irradiation is changed from low to high and then to low again. Figs 9, 10, 11 and 12 present the output PV power and voltage for both methods (P&O and AFPID).

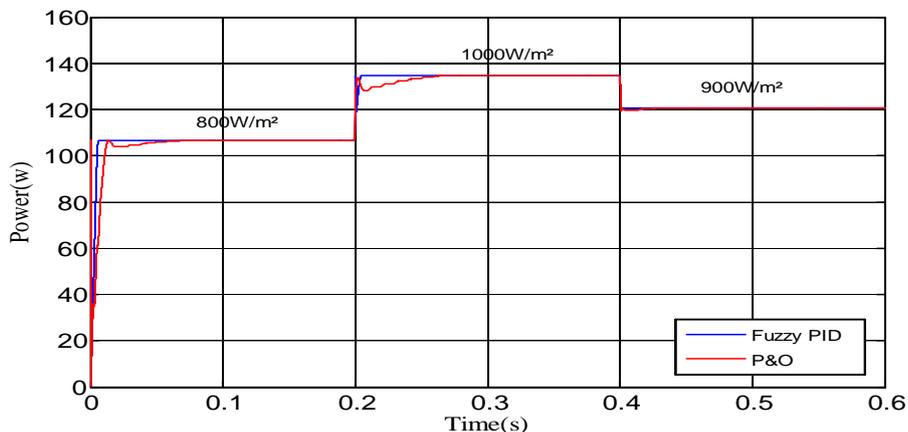


Fig. 9. The output power of PV panel under rapidly changing irradiation.

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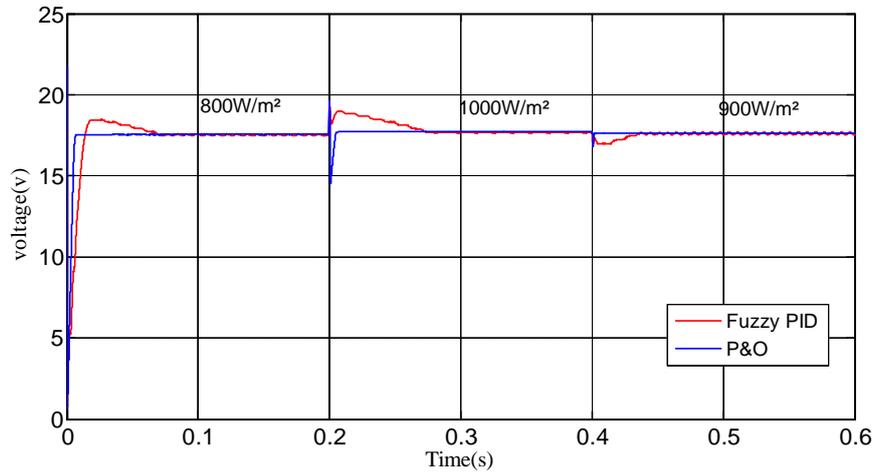


Fig. 10. The output voltage of PV panel under rapidly changing irradiation

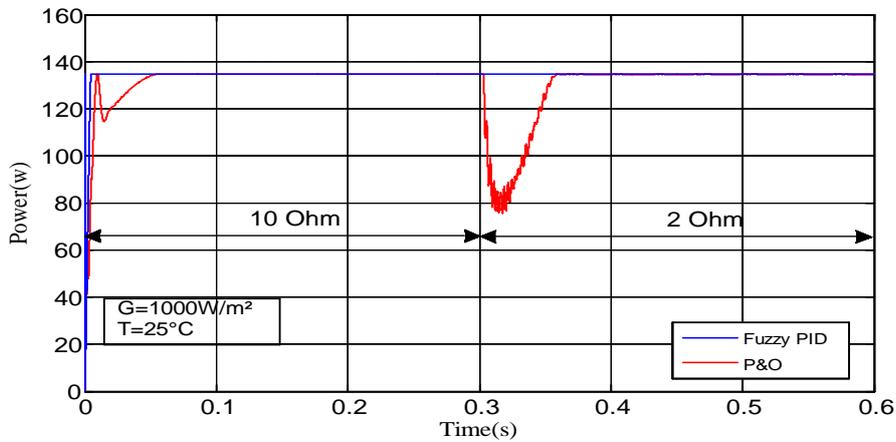


Fig. 11. The output power of PV panel under changing load.

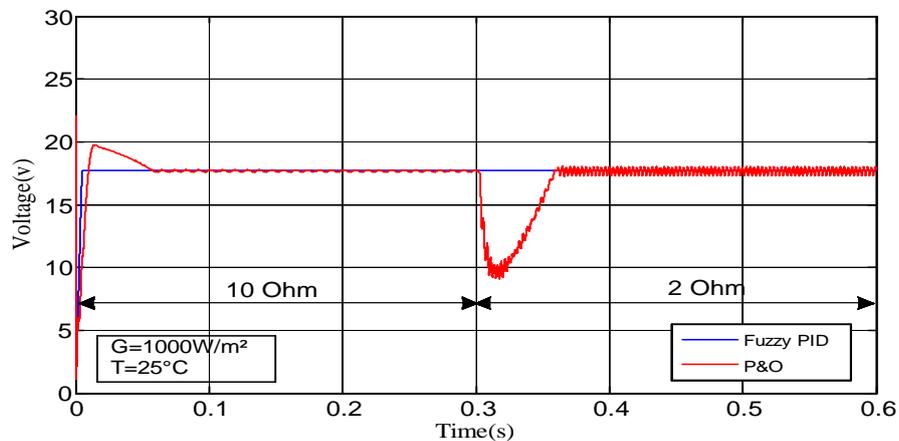


Fig. 12. The output voltage of PV panel under changing load

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A rapid increase in irradiance from  $800\text{W/m}^2$  to  $1000\text{W/m}^2$  respectively a decrease from  $1000\text{W/m}^2$  to  $900\text{W/m}^2$  with a time period of 0.2 seconds was simulated. The PV module temperature was maintained at a constant value of  $25^\circ\text{C}$ . To confirm the effectiveness of the proposed strategy a second simulation was made using a constant solar irradiation and temperature and changing load from 10 Ohm to 2 Ohm. From figs 9, 10, 11 and 12, it is clearly observed that both Adaptive Fuzzy PID controller and P&O control MPPT can track the maximum power point. We can also confirm with these tests that the Adaptive Fuzzy PID controller has better response time, less oscillation and much more accurate tracking at each step.

### VI. CONCLUSION

In this paper, an adaptive fuzzy PID based MPPT strategy is proposed. The design methodology and simulation of the proposed controller is discussed in detail in this paper. By combining the advantages of fuzzy logic and conventional PID control the proposed controller takes less time to track the maximum power point with accuracy. Simulation results demonstrate that the designed controller presents good results as it successfully tracked MPPT under rapid changing weather conditions than the well-known P&O approach. Further work is being conducted on the overall system design and experimental implementation.

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