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Fuzzy Maximum Power Point Tracking Using different Membership functionsforPhotovoltaic Panels

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Abstract : Recently, Sustainable energy has appeared recently as one of the most efficient sources of electrical energy. Solar energy, which converts direct sun rays into electrical energy, is one of the most basic kind of renewable energy. Maximum power extraction in the presence of changing environmental conditions is one of the problems of solar energy transformation. The Weather conditions affectthe voltage, current, and consequently the maximum power extracted from PV panels. To raise the efficiency and reducing the tracking time of the system, it requests to work for PV panels at a Maximum Power Point (MPP). Under any environmental conditions, there is a different MPP. Solar irradiation, temperature, and load all affect the PV panel's output power. The control of a Photovoltaic system using fuzzy logic, intelligent Maximum Power Point Tracking (MPPT) is proposed in this study. Fuzzy MPPT systems have a rapid response to the changes in the environmental conditions and do not move with changes in circuit parameters. In this research, we compare different examples of membership functions like Triangular, PIShaped, and Gaussian combination with different roles. Simulation results show that the Pi-shaped membership function has the best performance compared to other types. Fuzzy MPPT controller based on PI-shaped membership function is designed and implemented using low-cost hardware. Experimental results confirmed the validity of the proposed MPPT system.

KEYWORDS: PV, MPPT, Boost converter, fuzzy logic, MATLAB/Simulink, PVSOL

Introduction

In Egypt, we are suffering from High fuel prices, Pollution, and global warming. The answer to all the former challenges is to resort to renewable energy like solar energy.
The government is spreading the largest solar station (Banan, Aswan) in the World that will bring nearly 2000 MW [1] and aims to produce 20% of Egypt's total electricity output of clean energy by 2022.
Solar panel's efficiency levels arelow (between 9% - 17%) [2]compared to the efficiency levels of other sustainable energy systems.
The main principle behind MPPT is to obtain the maximumout the power of photovoltaic cells by searching for the MPP by adjusting the duty cycle until the maximum power is obtained. The efficiency is maximized by keeping the operating point as close as possible to the MPP all the time by minimizing the tracking time.

Error! Reference source not found.presents the Schematic diagram of the Photovoltaic system configuration. The system consists of a PV panel, Pulse Width Modulation (PWM), DC-DC Boost converter [10], and a resistive load. The duty cycle of PWM is changing to reach MPP of Photovoltaic cells at different Irradiance and Temperature conditions.
Many MPPT methods have been brought out and implemented in literature, including perturb and observe (P&O), incremental conductance (IncCon)[3]-[5]ripple correlation control (RCC)[6].These techniques have high tracking precision under steady climate conditions (STC).However,it was observed some variation in tracking speed and tracking precision when

radiation changes.On the other hand,smart techniques such as fuzzy logic control (FLC)[7]-[10]neural networks [13], and genetic algorithms [14], have high precision and fast-tracking response.

The primary problem of using photovoltaic cells is the dependence on irradiance, temperature, and load [15]Thus, the main goal is to extract the maximum power from the PV panel at various environmental conditions.

In this paper.A fuzzy logic-based MPPT is used to keep the operating point as close as possible to MPP.

Different types of membership functions are used and the performance of each case is compared.

In other cases, it was found that the PI-shaped membership function gives the best performance in terms of low fluctuation in the output power.

This paper is composed as follows: In Section**II,**Solar Photovoltaic Modeling is described. Section**III**presents the Fuzzy logic Based MPPT controller. The proposed
Various forms of membership function systems are explained in Section **IV**. Section **Error! Reference source not found.**includes the simulationresults, and Section**Error! Reference source not found.**contains the conclusion.

I. Solar Photovoltaic Modeling

A photovoltaic cell generates sunlight into electrical energy directly. When solar radiation comes down to it, the electrical current is generated, which depends on the amount of irradiance G (W/m^2) and temperature T (K). An equivalent circuit of a photovoltaic cell is illustrated in **[16]**,**[17]** and **Error! Reference source not found.**, which consists of photocurrent I_{Ph} current source, diode D and R_S and R_{Sh} Series and parallel resistance (Ω), respectively. The photovoltaic current (output) is computed by:

$$\mathbf{I_{Pv} = I_{Ph} - I_{Sh} - I_D} \quad (1)$$

Where:

$\mathbf{I_{Pv}}$ **:** Photovoltaic Current (Ampere)

$\mathbf{I_{Sh}}$ **:** Shunt Current (Ampere)

$\mathbf{I_D}$ **:** Shockley diode Current (Ampere)

Photocurrent can be represented by:

$$\mathbf{I_{Ph} = [I_{SC} + K_1.(T - T_r)].\frac{G}{1000}} \quad (2)$$

Where T_r Is the reference temperature, $I_{SC}$is the short circuit current at T_r, G is the irradiance (W/m^2), K_1 the cells short-circuit current temperature coefficient, and T are the cell's operating temperature in Kelvin

By the Shockley diode equation, the current passing through the diode is modeled by the following equation:

$$\mathbf{I_D = I_o[e^{\left(\frac{V_D}{n.V_T}\right)} - 1]} \quad (3)$$

Where $V_D$is the voltage across Diode (Volt)$V_D = V_{Pv} + R_S.I_{Pv}$), I_O is the diode's reverse saturation current, $V_T$is Thermal Voltage (At 25 °CV_T = 25mV)

$$\mathbf{V_T = \frac{K.T}{q}} \quad (4)$$

Where K is Boltzmann constant (1.380649×10−23 J/K) and q is the electron's charge (1.602 176 634×10−19 C).
The current through the shunt resistor is expressed by:

$$\mathbf{I_{Sh} = \frac{V_D}{R_{Sh}} = \frac{V_{Pv}+R_S.I_{Pv}}{R_{Sh}}} \quad (5)$$

Error!

Fig.5illustrates

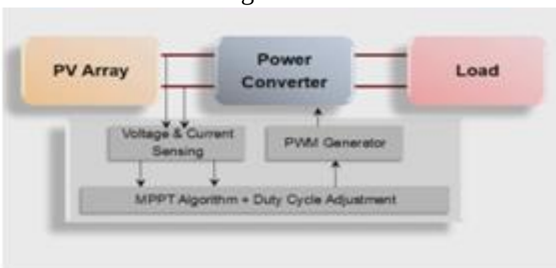

Fig.1

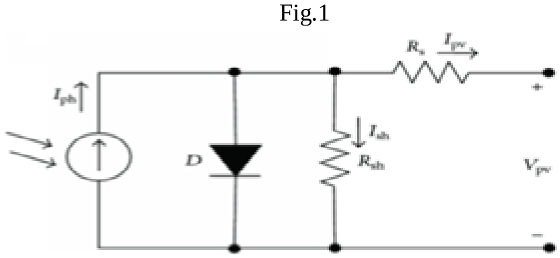

Fig.2

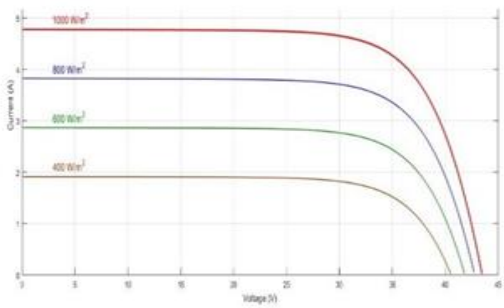

Fig.3

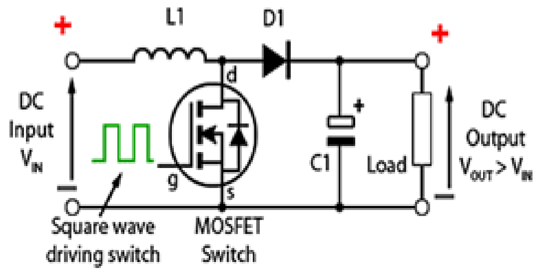

Fig.4

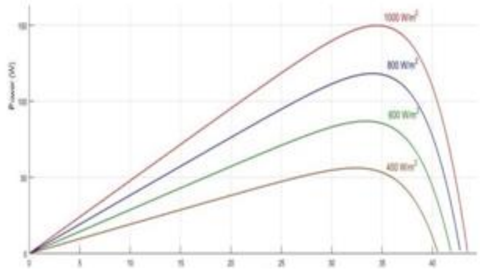

Fig.5P-

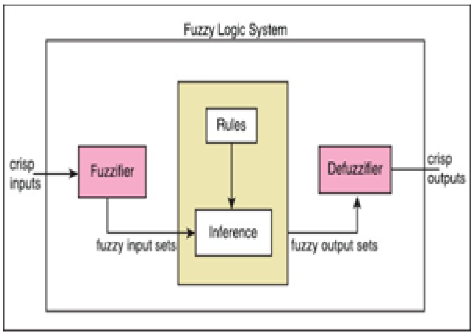

Fig.6

II.The

In Fig.6the fuzzy logic-based MPPT controller defuzzification [18]. In fuzzification, the crisp variables E(k) and CE(k) as

$$\mathbf{E(k)} = \frac{\Delta \mathbf{P}}{\Delta \mathbf{V}} = \frac{\mathbf{P(k)-P(k-1)}}{\mathbf{V(k)-V(k-1)}} \quad (6)$$

$$\mathbf{CE(k) = E(k) - E(k-1)} \quad (7)$$

$$\mathbf{D(k) = S_{\Delta D} \times \Delta D(k-1) - D(k-1)} \quad (8)$$

III.Fuzzy MPPT systemsusingvariousmembershipfunctions

The proposed fuzzy-based MPPT was simulated using different types of fuzzy sets [20]-[24]to compare the performance in each casewith 25 rules as shown in TABLE I. In the following sections, the different trials are elaborated.

Case (1) Triangular Membership Function

We used the Asymmetric membership function for error E(k) and changeof error CE(k) as shown inFig.7 andFig.8to convert inputvariables into fuzzy variables. Five linguistic terms are defined as input for both the error E(k) and change of error CE(k): NB (Negative Big), NS (Negative Small), ZE (Zero), PS (Positive Small), and PB (Positive Big) (Positive Big).On the other side, the change of duty cycle (ΔD) has seven fuzzy sets as in Fig. 9The fuzzy inference completed by utilizing Mamdani's method [18]with 25 rules as shown in TABLE I

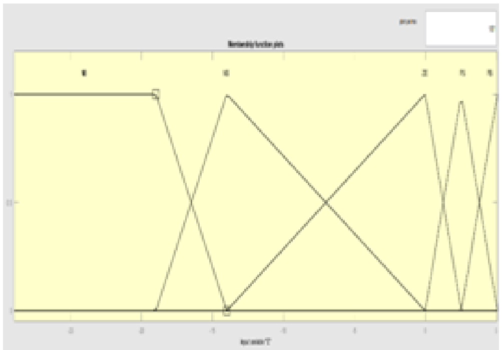

Fig.7 Error in Triangular Membership function

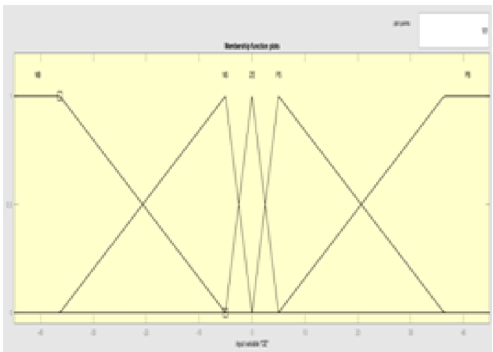

Fig.8Change Error in Triangular Membership function

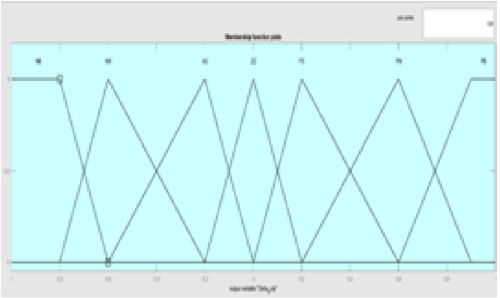

Fig. 9Change in Duty Cycle in Triangular Membership function

Case (2) PI-shaped Membership function

We tried the PI-shaped membership function [25]with five linguistic variables as input for the error (E) and change of error (CE) as shown in Fig.10 and Fig.11. Seven linguistic variables are utilized for the output (ΔD) as shown in Fig.12.

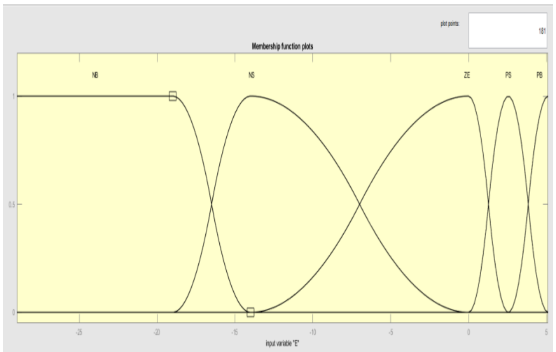

Fig.10Error in PI-Shaped Membership function

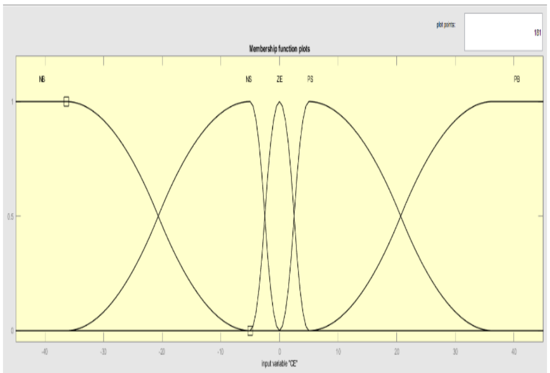

Fig.11 Change in Error in PI-Shaped Membership function

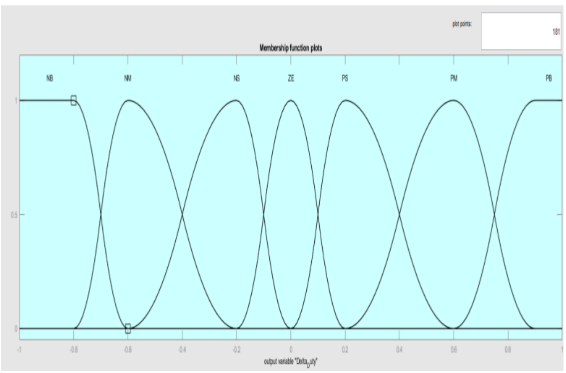

Fig.12Change in Duty Cycle in PI-Shaped Membership function

Case (3) Gaussian combination Membership function

We used the Gaussian combination membership function [25] with five linguistic variables as input for the error (E) and change of error (CE). Seven linguistic variables are utilized for the output (ΔD).

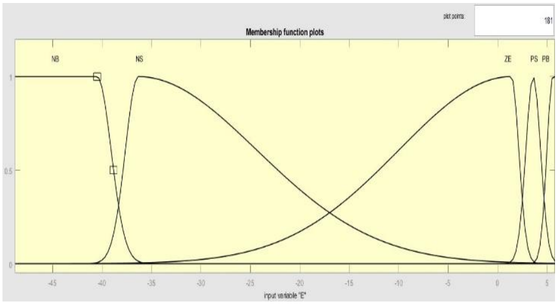

Fig.13Error in Gaussian Membership function

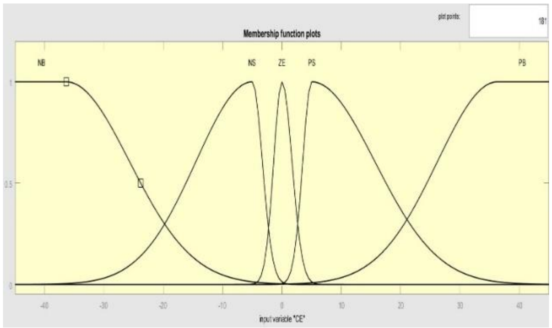

Fig.14 Change in Error in Gaussian Membership function

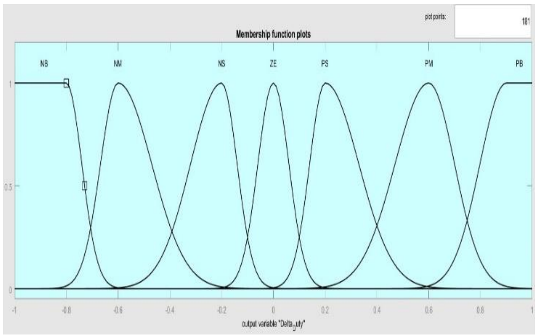

Fig.15Change in Duty Cycle in Gaussian Membership function

TABLE IThe rule table for FLC

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

1) Comparison between various Types of Membership Functions

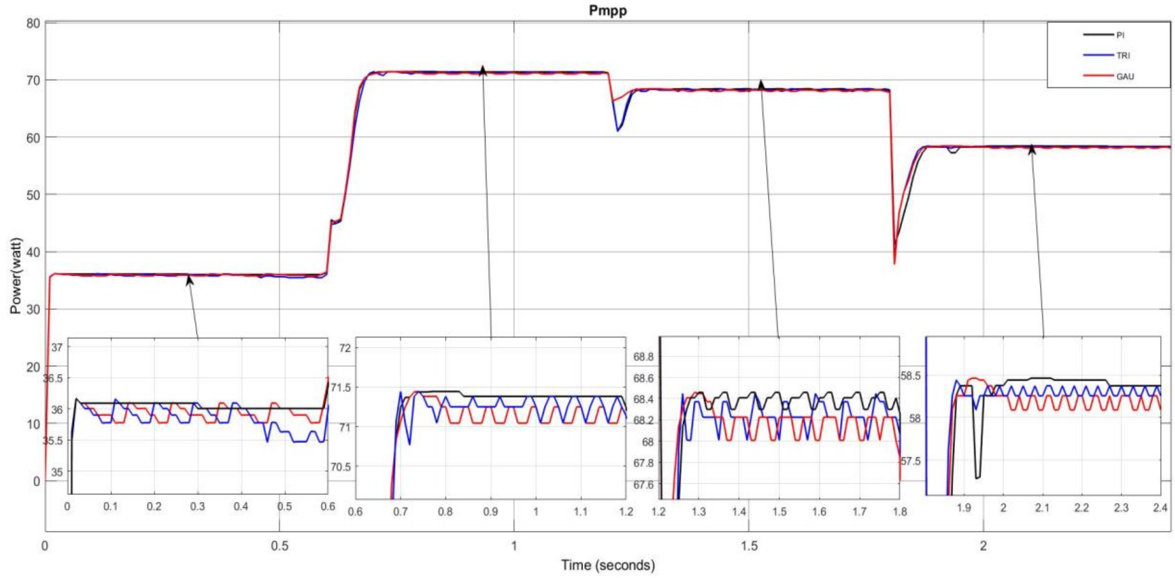

Fig. 16Efficiency Comparison between various types of Membership functions at maximum load Ro = 7 Ω

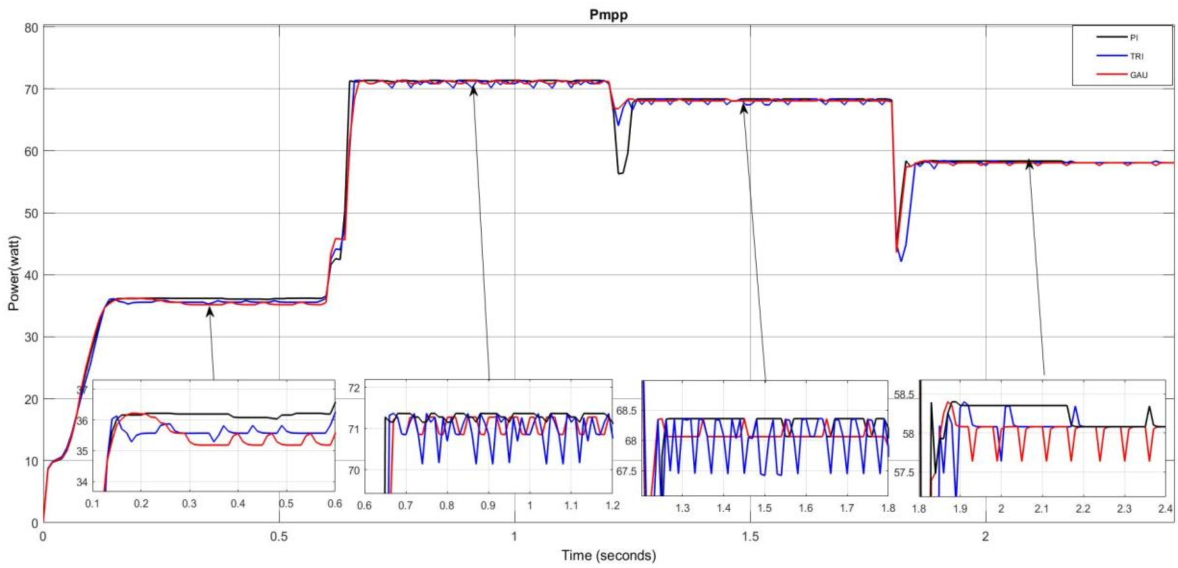

Fig. 17Efficiency Comparison between various types of Membership functions at maximum load R_o = 35 Ω

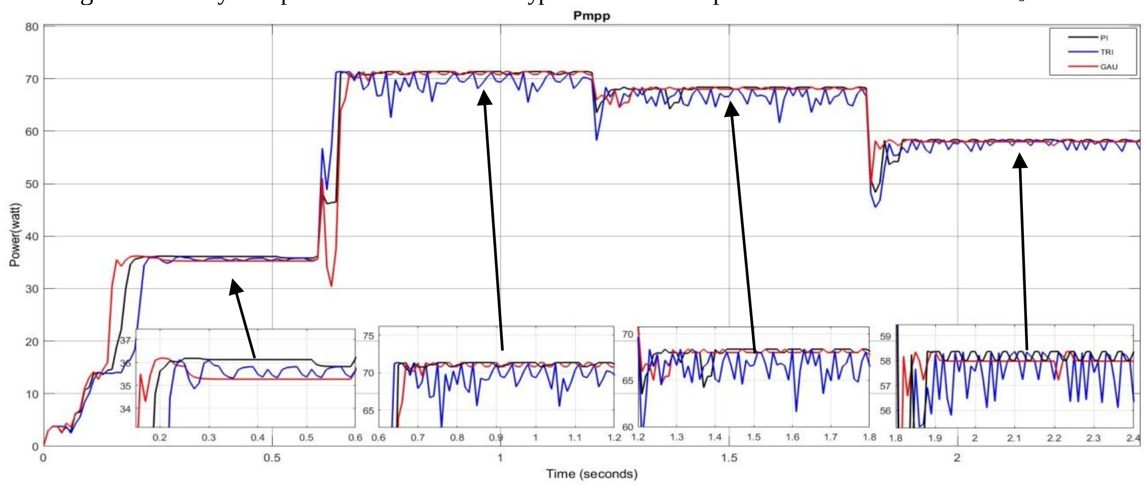

Fig. 18Efficiency Comparison between various types of Membership functions at maximum load R_o = 100 Ω

In this section, we compare the efficiency of the fuzzy-based MPPT using different types of Membership function at various [(431W/m^2, 20ºC) -(878 W/m^2, 32 ºC) -926 W/m^2, 55ºC) -(691W/m^2, 21 ºC)], The Electrical Characteristics of the PV panel used in the simulations shown inTABLE II.

Fig. 16and

TABLE IIIhasshown that the PI-Shaped membership function at different conditions is the best solution to get maximum power and fewer ripples, but at (926 W/m2, 55ºC) triangular membership function has the best solution.

As shown in Fig. 17andTABLE IVPI-Shaped membership function at different conditions gives better results withfewer ripples, but at (926 W/m2, 55ºC) Gaussian Combination membership function has the best results.

From Fig. 18andTABLE Vat(431W/m2, 20ºC) is shown that the Gaussian Combination membership function, but for the remaining conditions,the PI-Shaped membership function gives better results than the other membership functions also with fewer ripples.

TABLE IIElectrical Characteristics of PV panel 83 Watt

Maximum Power ($\mathbf{P_{MAX}}$)	83 W
Voltage at $\mathbf{P_{MAX}}$ ($\mathbf{V_{MAX}}$)	16.5 V
Current at $\mathbf{P_{MAX}}$ ($\mathbf{I_{MAX}}$)	5.07 A
Open circuit voltage ($\mathbf{V_{O.C}}$)	19.7 V
Short circuit current ($\mathbf{I_{S.C}}$)	5.78 A
Temperature coefficient of $\mathbf{I_{S.C}}$	0.058%/℃
Temperature coefficient of $\mathbf{V_{O.C}}$	-0.355%/℃
Cells per module (Ncell)	32

TABLE III. Average power at $R_o = 7\Omega$

Avg.Power	$R_o = 7\Omega$		
	PI	Gau.	TRI.
431 W/m^2, 20 ºC	36.05 W	35.94 W	35.84 W
878 W/m^2, 32 ºC	69.28 W	69.11 W	69.06 W
691 W/m^2, 21 ºC	57.78 W	56.84 W	57.06 W
926 W/m^2, 55 ºC	68.02 W	68.10 W	68.13W

TABLE IVAverage power at $R_o = 35\Omega$

`Avg.Power	$R_o = 35\Omega$		
	PI	Gau.	TRI.
431 W/m^2, 20 ºC	32.45 W	32.04W	32.07W
878 W/m^2, 32 ºC	69.57 W	69.33 W	69.39 W
691 W/m^2, 21 ºC	57.89W	57.63 W	57.22W
926 W/m^2, 55 ºC	67.62 W	68.02W	67.77W

TABLE V Average power at $R_o = 100\Omega$

Avg.Power	$R_o = 100\Omega$		
	PI	Gau.	TRI.
431 W/m^2, 20 ºC	28.3 W	28.98 W	26.84 W
878 W/m^2, 32 ºC	69.51W	68.59W	67.14W
691 W/m^2, 21 ºC	57.52 W	57.44 W	57.03W
926 W/m^2, 55 ºC	68.04 W	67.64 W	66.33W

IV. Conclusion

In this paper, a fuzzy-based MPPT is introduced. The performance in terms of the average output power and ripples is investigated for different membership functions. MATLAB/Simulink simulations were conducted using triangular, PI-Shaped, and Gaussian combination membership functions. Simulation results showed that PI-shapedgives better results than the other two membership functions regarding smooth operation and maximum Power.The fuzzy-based MPPT using PI-shaped membership function has fewer ripples in the output power, especially when the output current is low(higher output resistive load) as shown inFig. 16,Fig. 17,Fig. 18,

TABLE III,TABLE IV,and TABLE V.Consequently, among the tested membership functions,the PI-shaped membership function is recommended to be used in MPPT application.

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