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Design and realization of a fuzzy logic-based MPPT controller for PV systems using microcontroller

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ABSTRACT

This study presents a microcontroller-based fuzzy logic control method for maximum power point tracking (MPPT) in photovoltaic systems under varying temperature and solar irradiation. The proposed controller is implemented on an 8-bit microcontroller and regulates the duty cycle of a pulse-width-modulation-driven DC-DC converter to extract maximum power from the photovoltaic array. Unlike conventional MPPT methods, the fuzzy logic approach provides faster response, improved flexibility, and stronger robustness against nonlinear current-voltage characteristics and converter switching effects. The system includes a photovoltaic array, sensing circuits, a DC-DC converter, and an embedded controller programmed with optimized C code for real-time operation. Experimental results show that the proposed method reaches the maximum power point quickly and maintains stable performance during environmental changes. It also improves energy conversion efficiency compared with traditional algorithms. Its low-cost hardware and simple embedded implementation make it suitable for practical photovoltaic applications and sustainable energy generation in renewable energy systems.

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1. INTRODUCTION

Significant obstacles to sustainable development include the depletion of fossil fuel resources, the growing demand for energy worldwide, and reliance on imported primary energy sources [1]. As a result, renewable energy has become a practical option, with solar energy being one of the most plentiful and promising. India has significant solar potential; it receives around 5,000 TWh of solar energy per year, and the majority of its regions have solar insolation values between 4 and 7 kWh/m²/day [2]-[4]. Scalability, reduced installation time, and compatibility for both grid-connected and standalone applications are some benefits of using this resource with photovoltaic (PV) technology [5]. Solar energy is a dependable choice from the standpoint of energy security since even a small portion of the nation's solar resources can satisfy its electrical needs [6], [7].

Notwithstanding these benefits, environmental variables including temperature, irradiance, shading, and load conditions have a significant impact on the highly nonlinear performance of PV modules [8]. Maximum power point tracking (MPPT) approaches are used to extract the maximum possible power from PV systems in order to guarantee efficient functioning [7]. Traditional MPPT techniques like incremental conductance (IC) and perturb and observe (P&O) have drawbacks such steady-state oscillations and decreased accuracy in situations with fast environmental changes [9], [10]. Because it can manage nonlinear systems, ambiguous inputs, and changing operating circumstances without the need for a precise mathematical model, fuzzy logic control has become a viable substitute [11].

The article details the process of creating a MPPT system for a PV array using a microcontroller and fuzzy logic controller (FLC). Optimal sensing circuits, a PV array, and a pulse width modulation (PWM)-controlled DC-DC boost converter make up the hardware arrangement [12]. FLC improve energy conversion efficiency and reduce tracking time by dynamically adjusting the converter duty cycle to operate at the MPP [13], [14]. This setup makes use of the 14.2% efficient Kyocera KC200GHT-2 PV module. The dependability of Kyocera modules has led to their widespread use in PV systems across Asia, whether for residential, commercial, or industrial purposes [15], [16]. In order to build the fuzzy inference system, membership functions, and rule base, as well as conduct analyses, the fuzzy logic algorithm was created and tested in MATLAB [17]. The experimental results show that the suggested controller outperforms traditional MPPT approaches [18]-[20] by achieving a more rapid and steady convergence to the MPP under different environmental conditions.

This article is structed ed as follows: in section 2, the foundational concepts of the MPPT and FLC are outlined. In section 3, the design and implementation of the proposed study system are detailed. In section 4, the mathematical modelling of the study system is presented. In section 5, the proposed algorithm and flowchart are explained. In section 6, the results of the simulation are analyzed. Finally, section 7 concludes the discussion and presents future directions.

2. PHOTOVOLTAIC MAXIMUM POWER POINT TRACKING AND FUZZY LOGIC

This this study was to attain the MPPT in response to varying load and environmental conditions. Traditional approaches, such as P&O and IC, frequently demonstrate oscillatory behavior and diminished efficiency. Conversely, fuzzy logic control provides enhanced precision, adaptability, and effectiveness, attaining MPPT efficiencies exceeding 98%.

The algorithm under consideration was formulated and executed using MATLAB for simulation purposes. Figure 1 depicts the variation in the maximum power with respect to temperature under constant irradiance conditions [21], whereas Figure 2 shows the impact of irradiance fluctuations at a fixed temperature. The objective is to consistently monitor the operating point that aligns with the MPP [22]. Although PV systems are recognized as sustainable energy solutions, they face several challenges, including emissions from component manufacturing, elevated installation costs, and a maximum module efficiency of approximately 22%. Figure 3 illustrates the schematic configuration, in which the PV module supplies i & v to a variable load R_0. The resistance equivalent from the PV side is represented as R_t. The direct connection of the PV module to the load does not ensure optimal power extraction; therefore, a power interface is necessary [23]. Figure 4 illustrates that the maximum power is achieved exclusively when R_t equals R_0, thereby fulfilling the specified condition [24], [25].

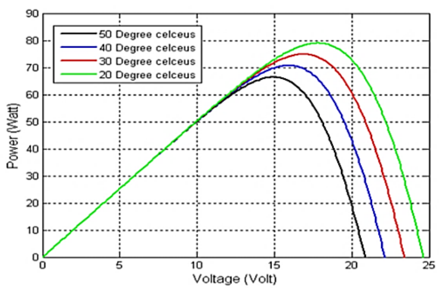

Figure 1. P_{max} varies with different cell temperature at the same insolation

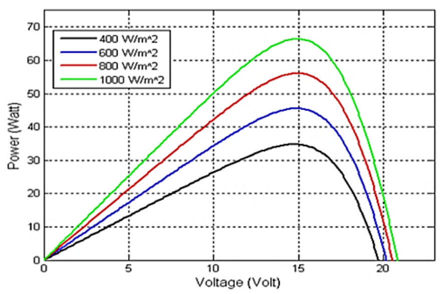

Figure 2. P_{max} varies with different isolation at the same temperature

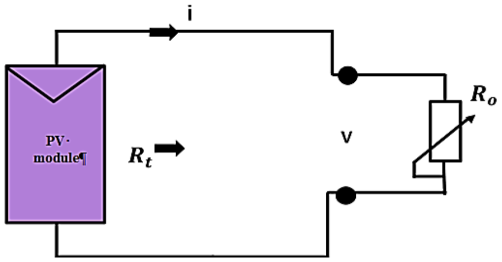

Figure 3. Circuit diagram

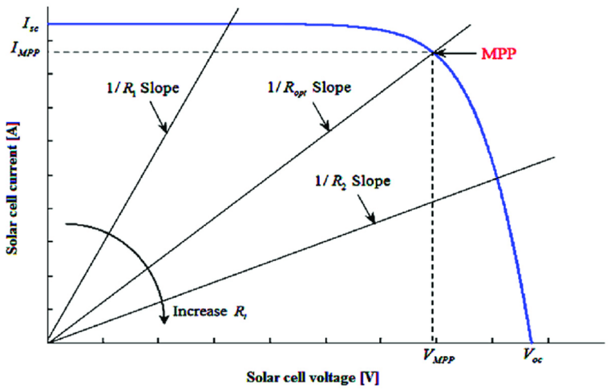

Figure 4. V-I characteristics of PV

Load variations shift the operating point away from the MPP and necessitate a dynamic adjustment of the operating conditions, as given by (1):

$$V_{MPP}\ X\ I_{MPP} = P_{max} \tag{1}$$

Fuzzy logic control is well suited to this task because it handles uncertainty and imprecision more effectively than Boolean logic. Membership functions represent linguistic variables, such as "low," "medium," and "high," with values between 0 and 1. As shown in Figure 5, the control process involves fuzzification, decision-making through rule evaluation, and defuzzification to produce a crisp output. The fuzzy algorithm adaptively adjusts the *D* of the DC-DC converter to ensure accurate, stable, and real-time convergence to the MPP under varying conditions.

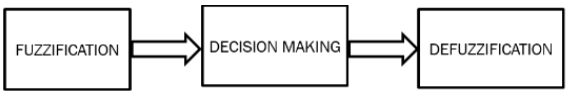

Figure 5. Implementation of fuzzy logic

3. STUDY SYSTEM

In PV systems, fluctuations in irradiance and temperature often cause the operating point to deviate from the MPP. To reduce energy loss, it is essential for the tracker to exhibit rapid and precise responsiveness; however, this is complicated by the nonlinear properties of PV cells. A proposed solution to this challenge involves the implementation of an MPPT scheme utilizing a boost DC-DC converter combined with FLC, as demonstrated in Figure 6. This methodology integrates voltage-power feedback with advanced computational techniques, facilitating a dual-dimensional tracking strategy that improves dynamic responsiveness and optimizes power delivery to the load.

To measure the MPP, the boost converter's metal–oxide–semiconductor field-effect transistor (MOSFET) switch is driven by a PWM signal with a *D* that can be adjusted. FLC offers a versatile technique that does not necessitate a perfect mathematical model, in contrast to conventional control approaches that frequently encounter challenges when trying to simulate nonlinear system dynamics. This work validates the implementation of the FLC on a microcontroller through experimental studies and MATLAB simulations. Using the right sensors, the voltage and current of the PV modules are measured to start the control process. The controller receives these analogue signals after they have been digitally converted by an ADC. In order to achieve and sustain operating at the MPP, the fuzzy logic algorithm assesses the discrepancy between the reference and real values and modifies the *D* appropriately. Achieving optimal performance is all about getting the feedback signal very close to the reference value. The controller generates PWM pulses for the MOSFET, thereby regulating the boost converter, adjusting the PV output voltage, and facilitating continuous maximum power extraction under varying environmental conditions.

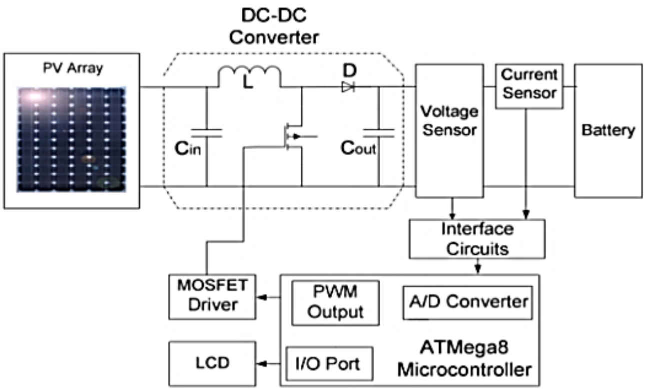

Figure 6. Proposed scheme of a boost DC-DC converter, MPPT with FLC

4. MATHEMATICAL MODELING

4.1. Requirement and specifications

With a peak P_o of 200.143 W and an efficiency rating of 14.2%, the proposed MPPT system made use of a Kyocera Solar KC200GT PV module. The module's V_{OC} was 32.9 V and its I_{sc} was 8.21 A; at 26.3 V and 7.61 A, it performed at its peak. Along with a maximum system voltage of 1,000 V and temperature coefficients of -1.23×10^{-1} V/°C for V_{oc} and 3.18×10^{3} A/°C for I_{sc}, further electrical parameters include a NOCT of 47 °C. Dimensions of 1425 mm×990 mm×36 mm, weight 18.5 kg, and cable lengths +910 mm and-710 mm were part of the mechanical criteria. The installation processes were also supported.

The module's 54 polycrystalline rectangular cells were strategically placed to maximize surface usage and energy conversion. To address PV system nonlinearity, an FLC with five membership functions was created. The fuzzy MPPT algorithm had a 98% efficiency, enabling fast and precise convergence to the MPP under diverse irradiance and temperature situations. A 90%-efficient DC boost converter was used for power conditioning. The specifications provide a framework for modeling, simulation, and microcontroller-based implementation of the fuzzy logic MPPT system, ensuring efficient and dependable solar energy use. The electrical specifications of the cell were tested under 1 kW/m² irradiance, 1.5 air mass spectrum, and 25 °C cell temperature.

4.2. Technical specification of photovoltaic panel

A consistent framework for gauging solar PV module performance is provided by STC. The optimal circumstances for sunlight are described by these parameters: cell temperature of 25 °C, solar irradiation of 1000 W/m², and air mass (AM) of 1.5. On the other hand, nominal operating cell temperature (NOCT) is a more accurate representation of actual working circumstances, which are usually set at 20 °C with an irradiation of 800 W/m² and a wind speed of 2.24 mph. When applied to actual climatic circumstances, these metrics provide a realistic assessment of PV module performance. The specifications of the PV module are outlined in the previous section. The PV module transforms incoming solar irradiance into electrical energy and acts as the main voltage source for the load. A fuzzy logic-based algorithm for the MPPT was implemented to optimize power extraction. The PV module was connected to a non-isolated DC-DC boost converter, which increased the voltage level and supplied it to the voltage measurement block. A diagram of the converter is presented in Figure 7, detailing the component values as C_m=4000 μF, C_{out}=50 μF, and L=100 μH. The core equation that defines the boost converter is presented as in (2):

$$\frac{V_{out}}{V_{in}}=\frac{1}{1-D} \tag{2}$$

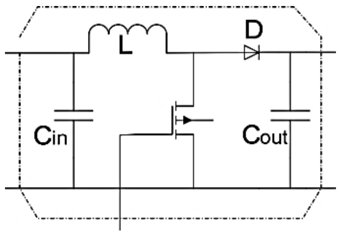

Figure 7. DC-DC converter

Here, *D* is the duty cycle that owing to the dynamic nature of the duty cycle, C_{in}, C_{out}, and *L* cannot be established precisely in advance; instead, their values are determined based on the maximum operational constraints. There are two separate modes of operation for the converter: when the switch is open, the current through the inductor grows linearly but the diode is turned off. When the switch is closed, the energy stored in the inductor is transferred to the output circuit via the diode. Table 1 presents the nominal ratings of PV modules at 12 V, 20 V, and 24 V levels. The modules contain 36, 60, and 72 cells respectively, with open-circuit voltages of 22 V, 38 V, and 46 V, and maximum power voltages of 18 V, 31 V, and 36 V.

Table 1. Nominal rating of PV modules at different voltage levels

Nominal	12 V	20 V	24 V
Number of cells	36	60	72
Open circuit voltage (V_{oc})	22 V	38 V	46 V
Max power volts (V_{MPP})	18 V	31 V	36 V

Figure 8 depicts the ideal operating point that the MPPT algorithm is required to monitor. The criterion for achieving maximum power is derived by taking the derivative of *P* w.r.t. *V* and setting it to *0*, represented as in (3):

$$\frac{dP}{dV} = \frac{P(n)-P(n-1)}{V(n)-V(n-1)} \tag{3}$$

- Case-1: when dP/dV=0, the operating point corresponds to the MPP.
- Case 2: when dP/dV>0, the operating point lies to the left of the MPP.
- Case 3: when dP/dV<0, the operating point lies to the right of the MPP.

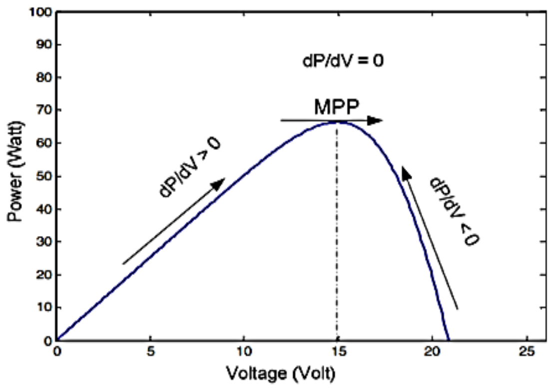

Figure 8. Maximum point tracking

The application of fuzzy logic control demonstrates significant efficacy in managing the nonlinear characteristics of PV systems, particularly in scenarios in which traditional algorithms and microcontrollers face constraints. By utilizing artificial intelligence, fuzzy rules markedly decrease the tracking duration and attain accuracies surpassing 98%.

5. DETAILED ALGORITHM AND FLOWCHART

Table 2 presents the designed algorithm of the system. Five membership functions were defined in total. Where, $\Delta P_{pv}[i/p]$ denotes Input-1, $\Delta V_{pv}[i/p]$ denotes Input-2 and $\Delta V_{pv}*[o/p]$ denotes output. In membership function, NB is the negative big; NS is the negative small; ZE is the zero; PS is the positive small and PB is the positive big.

Table 2. Algorithm

ΔVpv*[o/p]		ΔVpv[i/p]				
ΔPpv[i/p]		NB	NS	ZE	PS	PB
	NB	PS	PB	NB	NB	NS
	NS	PS	PS	NS	NS	NS
	ZE	ZE	ZE	ZE	ZE	ZE
	PS	NS	NS	PS	PS	PS
	PB	NS	NB	PB	PB	PS

A total of 25 rules were set in MATLAB Simulink for the implementation of the algorithm. The fuzzification of the inputs occurs, and decisions are made by the system according to the rules, followed by the output. The Rule Editor Toolbox is a MATLAB Simulink Library. The inputs and outputs are defined as shown in the algorithm above. The rule base is defined such that the FLC can make the appropriate decision. The inputs and outputs are in the form of membership functions, namely, NB, NS, ZE, PS, and PB. Figure 9 shows a detailed flowchart of the algorithm and its working, from step 1 to step 6.

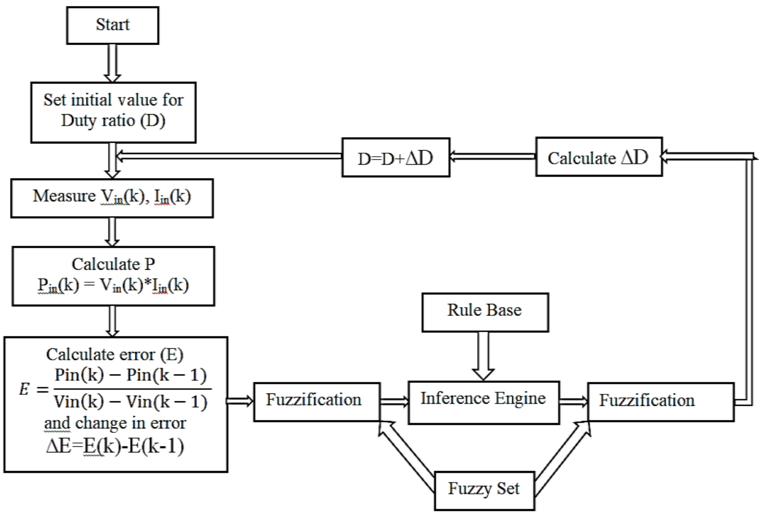

Figure 9. Detailed flowcharts

Step 1: start the system. Assume that the PV module delivers power at any point during operation.
Step 2: initialize the value of D. In the begin let it be equal to zero. D is the controlling parameter and is responsible for the change in the required output.
Step 3: calculate P which is initially obtained after starting the system. To calculate power, (4) is used, assuming a DC system.

$$P_{in}(k)=V_{in}(k)*I_{in}(k) \quad (4)$$

where $P_{in}(k)$ is the input power, $V_{in}(k)$ is the input voltage to the system, and $I_{in}(k)$ is the input current.
Step 4: the next step is to calculate error (E), Error is the difference between present state (k) and the previous state (k-1) in discrete domain. Error is calculated by using (5):

$$E = \frac{\mathrm{Pin(k)-Pin(k-1)}}{\mathrm{Vin(k)-Vin(k-1)}} \quad (5)$$

In addition, ΔE (change in error) was calculated using (6);

$$\Delta E = E(k) - E(k-1) \tag{6}$$

Step 5: this error signal is provided to the controller, where fuzzy logic is embedded. Fuzzification of the error signal is performed, and the resulting values are divided into membership functions. The inference engine is the decision-making block. A decision is made according to the algorithm, which comprises the rules embedded in the rule base. After the output membership function is determined according to the input, defuzzification is performed, and the final output is calculated.
Step 6: finally, ΔD is calculated as the difference amongst the previous and present values to determine the change in the duty ratio, and the new D is calculated by $D=D+\Delta D$ and the output is updated. If the D does not match the desired value, the process is repeated.

6. SIMULINK AND RESULTS

The Kyocera Solar KC200GT PV module was chosen for examination because of its dependable performance attributes. In the Simulink model, it was assumed that both series and parallel strings operated at unity. In the context of fuzzy logic for the MPPT, two input variables were established: dP_{pv}, representing the change in PV power, and dP_{pv}, representing the change in PV voltage.

Controller output is shown as (dP_{pv} *, indicating output voltage fluctuation. In Figure 10, membership functions for dP_{pv}, are symmetrically distributed over the interval ([-8.5, 8.5]) using five linguistic variables: NB, NS, ZE, PS, and PB In Figure 11, the membership functions for the input variable defined inside the range ([-1.6, 1.6]) are shown using the same linguistic terminology. The output membership function dP_{pv} * in Figure 12 has a symmetric distribution over the interval [-1.6, 1.6]. The FLC system in Figure 13 and the entire Simulink model in Figure 14 integrate the PV array, fuzzy controller, and DC-DC converter for accurate MPPT under different irradiance and temperature circumstances.

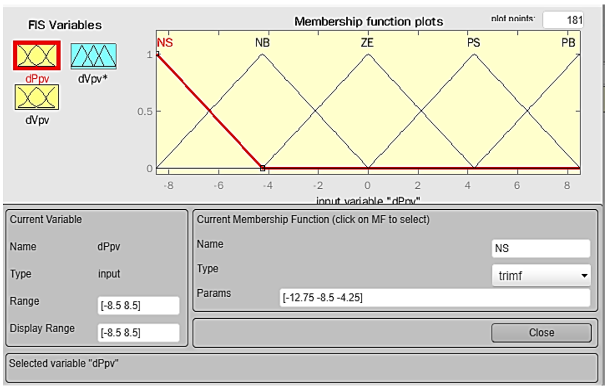

Figure 10. Input-1: dP_{pv}

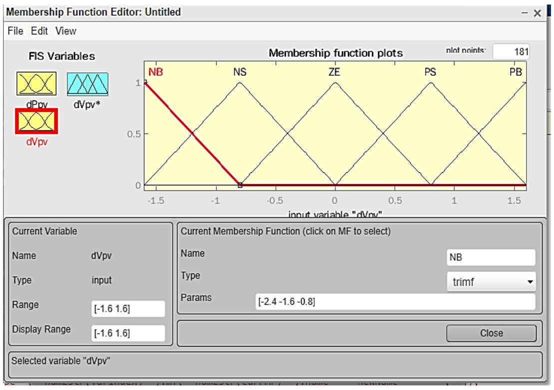

Figure 11. Input-2: dV_{pv}

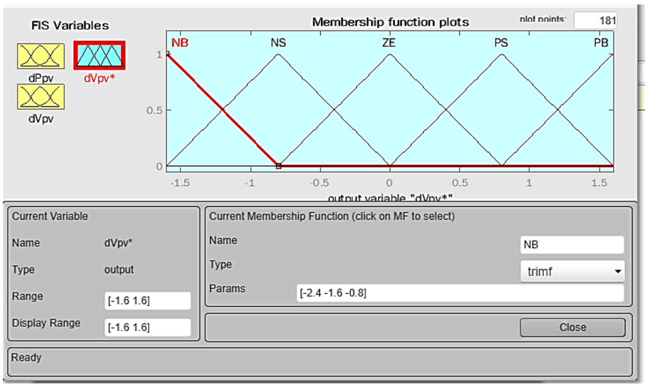

Figure 12. Output: dV_{pv}*

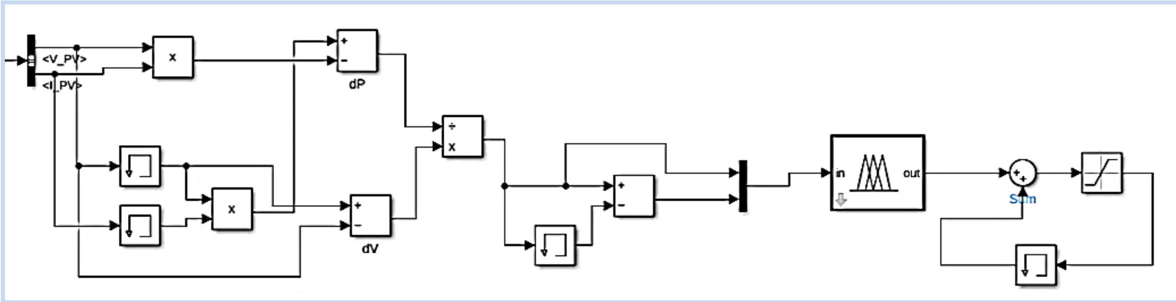

Figure 13. Fuzzy system

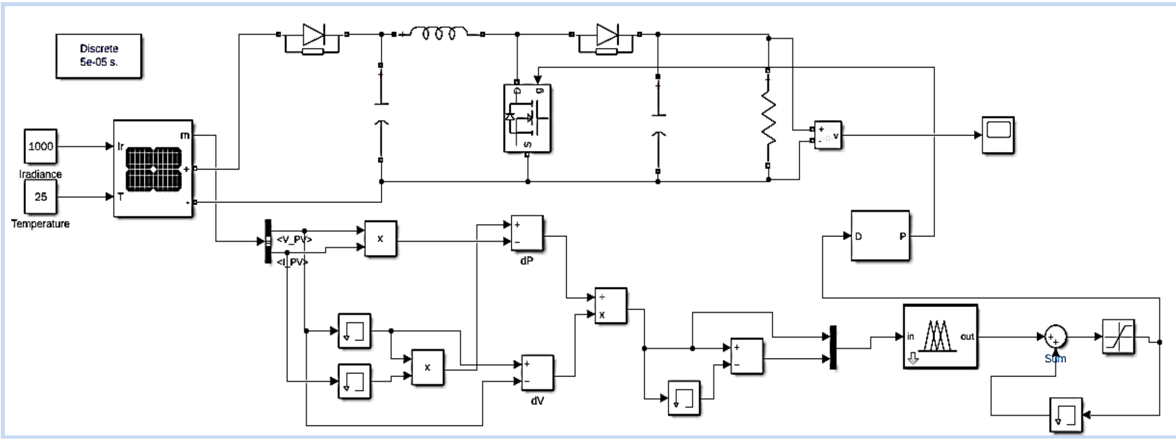

Figure 14. Simulink model of study system

A boost converter is used to step up the voltage. *D* is the varying parameter. By controlling the *D* of V_{MPP} at the V_{MPP} output is received and measured by the voltage measurement block. At the initial point, the product of *V* and *I* is needed from the PV module; hence, by using the product block, the power is calculated. Further memory elements are required to hold the previous values. Previous values are required to calculate the error to obtain the required output. Using the subtract block, the instantaneous value and previous values of power and voltage are obtained; that is, *dP* and *dV* are calculated. Further, using the division and multiplication block, *E* is calculated and expressed in (7), as shown in the flowchart.

$$E = \frac{Pin(k) - Pin(k-1)}{Vin(k) - Vin(k-1)} \tag{7}$$

These blocks are further connected to a FLC to implement the algorithm. The process is as follows: fuzzification, decision making, and defuzzification. Subsequently, it is connected to a saturation block to limit the output from −1 to +1, as the system is designed for a FLC. The output of saturation block is given to PWM generator to obtain desired duty cycle. The Simulink model was tested for the following cases: Case-1 constant temperature and variable irradiation; Case-2 constant irradiation and variable temperature; and Case-3 random inputs.

a. Case-1

In this case, the model was tested when the *t* was kept constant and the irradiation varied. The V_{MPP} was achieved even with a change in irradiation. Hence, the main motive was achieved.

Here, observations were obtained for three different irradiations: 400 W/m^2, 600 W/m^2, and 800 W/m^2 keeping the temperature constant at 25 ºC, as shown in Table 3. The same graph was obtained for all three inputs from Table 3. The outputs of the model are shown in Figures 15-17.

Table 3. Observation at constant temperature, variable irradiation

Temperature (°C)	Irradiation (W/m^2)
25	400
25	600
25	800

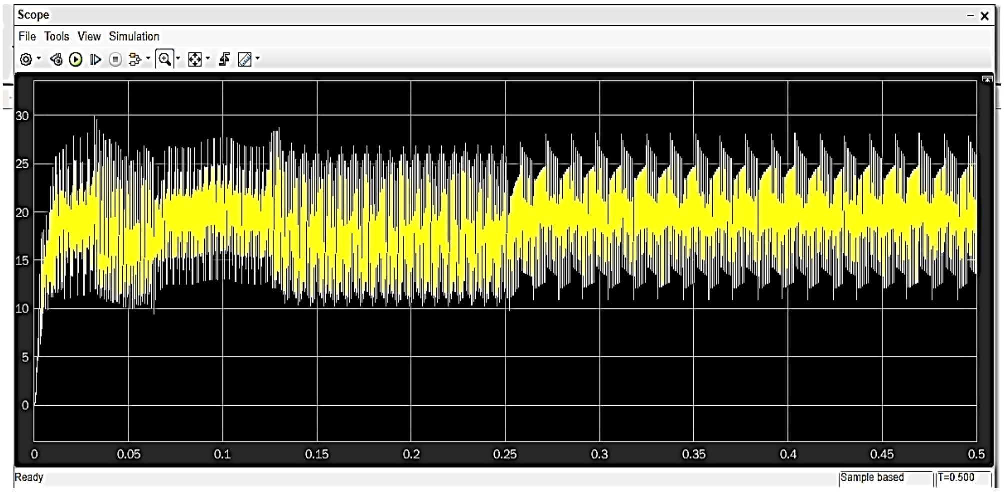

Figure 15. Output at 25 °C and 400 W/m^2

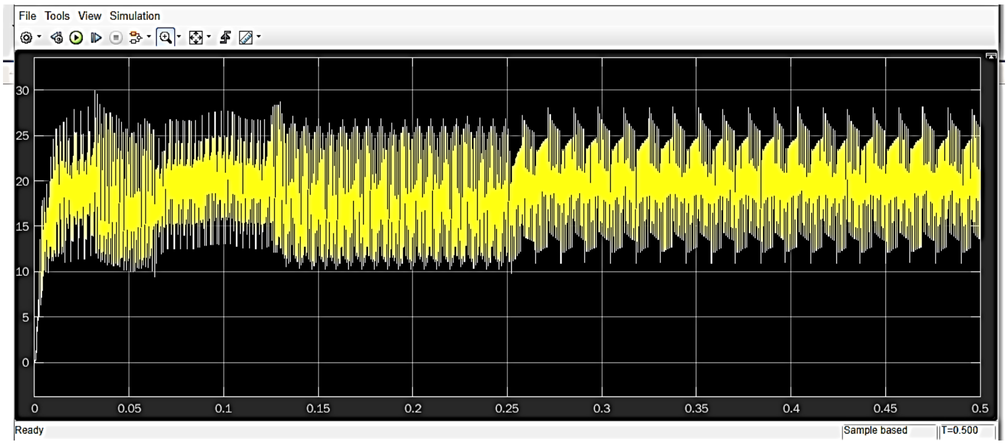

Figure 16. Output at 25 °C and 600 W/m^2

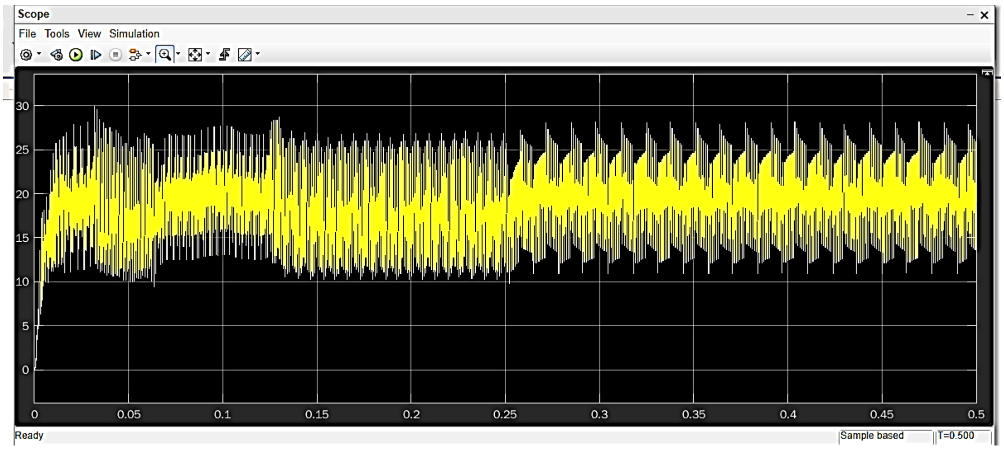

Figure 17. Output at 25 °C and 800 W/m^2

b. Case-2

In this case, the model was tested when the irradiation was kept constant and the temperature was varied. The VMPP was achieved even with a change in temperature, as shown in Table 4.

Table 4. Observation at constant irradiation, variable temperature

Temperature (°C)	Irradiation (W/m^2)
25	800
27	800
29	800

Here, observations were obtained for three different temperatures: 25 °C, 27 °C, and 29 °C, keeping the irradiation constant at 800 W/m^2. The same graph was obtained for all three inputs from Table 4. The outputs of the model are shown in Figures 18-20, respectively.

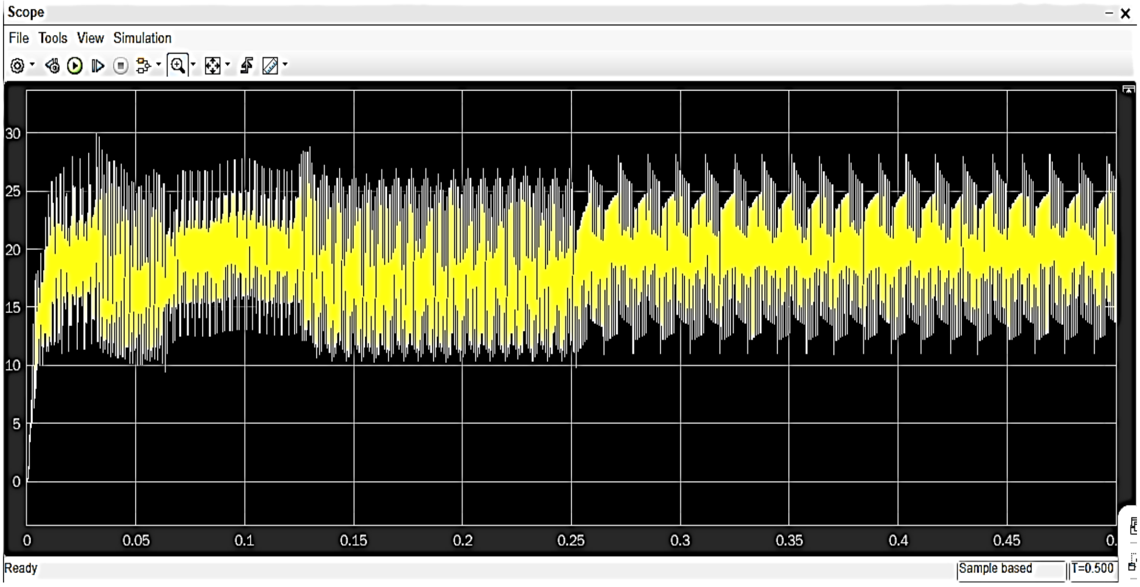

Figure 18. Output at 25 °C and 800 W/m^2

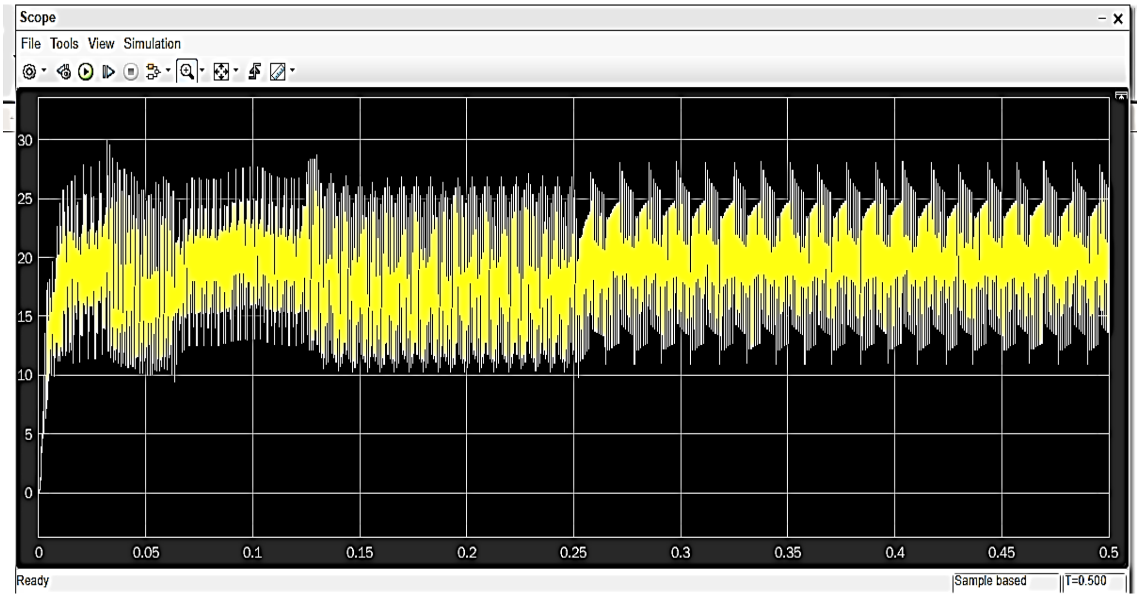

Figure 19. Output at 27 °C and 800 W/m^2

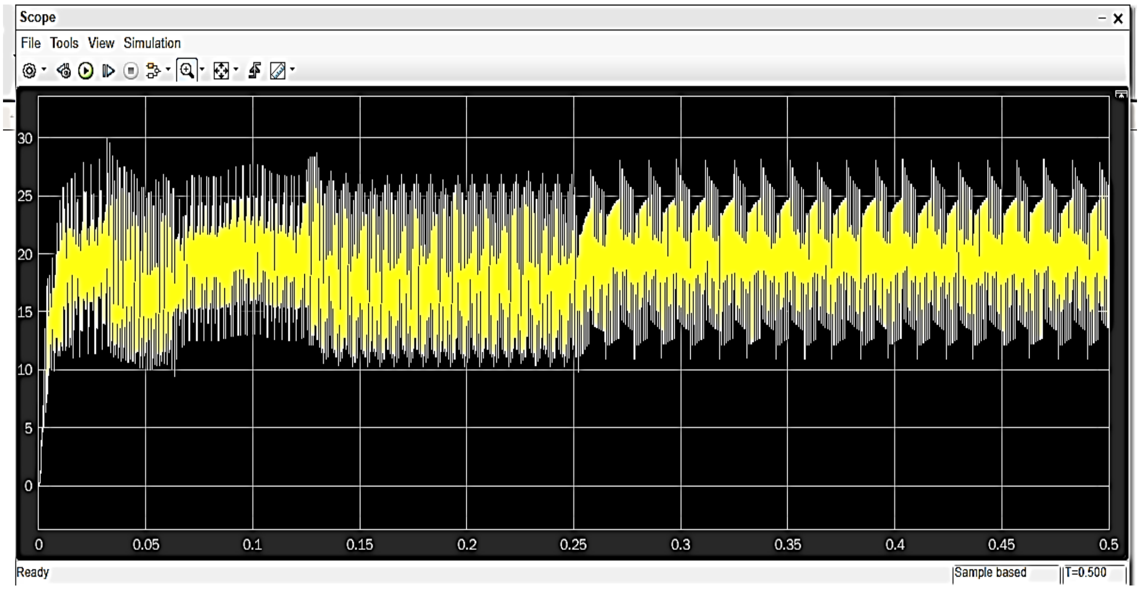

Figure 20. Output at 29 °C and 800 W/m^2

c. Case-3

In this case, random inputs were used, as listed in Table 5. The temperature was varied from 30 to 50 °C for rigorous testing. The irradiation was varied from 600 W/m^2 to 1000 W/m^2. It was observed that the VMPP was achieved even with a change in temperature.

The same graph was obtained for all six inputs from Table 5 and Figure 21 shows the output of the model for the random inputs. The output, that is, the graph and VMPP, does not change in any of the above cases. It is clear that MPP is achieved even when the temperature or irradiation changes.

Table 5. Random inputs

Temperature (°C)	Irradiation (W/m^2)
30	600
30	600
40	800
50	800
50	1000

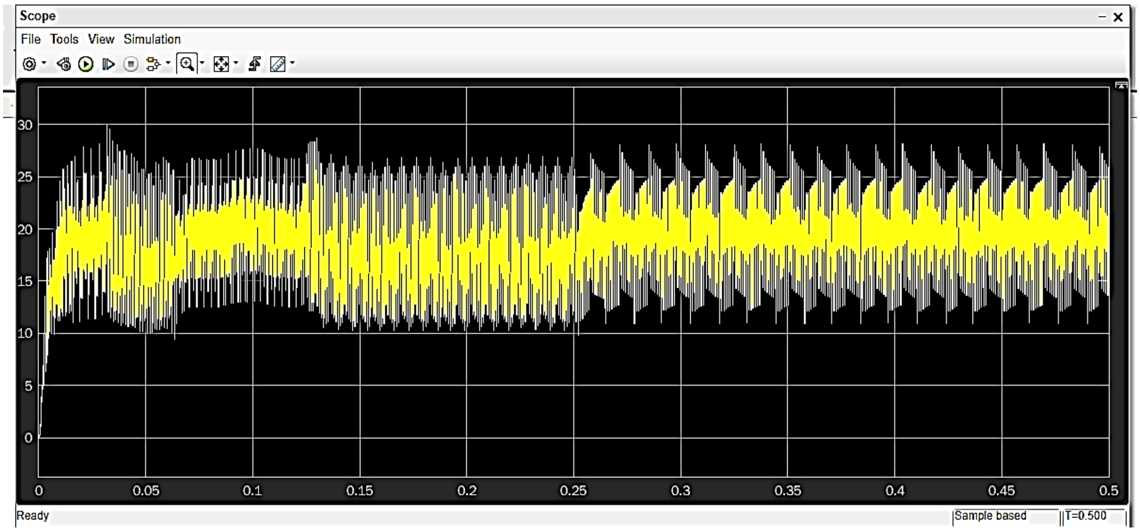

Figure 21. Output at random inputs

7. CONCLUSION

This study presents the application of a fuzzy logic-based MPPT technique for PV systems operating under varying temperature and irradiance conditions. A mathematical model and algorithm were formulated, and simulations were conducted using MATLAB/Simulink. Fuzzy rules were developed to guarantee a precise input-output mapping, thereby enabling the controller to operate consistently, even in the presence of uncertain or imprecise data. The fuzzy controller adeptly managed system nonlinearities, minimized the tracking time, and consistently ensured the stability of the VMPP under various operating conditions.

The results show that FLC, an artificial intelligent method, enhances PV system efficiency by enabling exact and effective maximum power extraction. The D control and a power interface enabled reliable tracking of the optimal operating point. PV systems create enough energy to meet a household's 5.7 kWh daily energy demands, and any extra can be sent to the utility grid. PV systems have high initial costs, but their low maintenance, reliability, return on investment, and sustainable energy output make them feasible and profitable. In summary, the implementation of fuzzy logic in the MPPT offers a reliable and effective approach to enhancing the performance of PV systems, and plays a crucial role in advancing clean and sustainable energy technologies.

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AUTHOR CONTRIBUTIONS STATEMENT

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Badal Kumar	✓			✓		✓	✓			✓		✓		
Alok Kumar		✓		✓		✓				✓				
Supriya Nilesh Thakur		✓			✓			✓	✓		✓			
Krupali Kanekar	✓				✓	✓		✓		✓				
Pranali M. Thakre		✓	✓						✓					
Prashant K. Magadum	✓		✓						✓		✓	✓		

C : **C**onceptualization	I : **I**nvestigation	Vi : **Vi**sualization
M : **M**ethodology	R : **R**esources	Su : **Su**pervision
So : **So**ftware	D : **D**ata Curation	P : **P**roject administration
Va : **Va**lidation	O : Writing - **O**riginal Draft	Fu : **Fu**nding acquisition
Fo : **Fo**rmal analysis	E : Writing - Review & **E**diting	

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

REFERENCES

[1] T. M. de Lima and J. A. C. B. Oliveira, "FPGA-based fuzzy logic controllers applied to the MPPT of PV panels—A systematic review," *IEEE Transactions on Fuzzy Systems*, vol. 32, no. 8, pp. 4260–4269, Aug. 2024, doi: 10.1109/TFUZZ.2024.3392846.
[2] J.-S. Ko and D.-H. Chung, "The MPPT control of PV system using the series-connected PI controller," in *Proceedings of the 16th International Conference on Control, Automation and Systems (ICCAS)*, Gyeongju, South Korea, 2016, pp. 807–809, doi: 10.1109/ICCAS.2016.7832406.
[3] A. Najmurrokhman, Kusnandar, U. Komarudin, A. Daelami, and F. Adiputra, "Design and implementation of temperature and humidity control system in oyster mushroom cultivation using fuzzy logic controller," in *Proceedings of the 2019 International Conference on Computer, Control, Informatics and Its Applications (IC3INA)*, Tangerang, Indonesia, 2019, pp. 146–150, doi: 10.1109/IC3INA48034.2019.8949573.
[4] A. Kushnir, B. Kopchak, and V. Oksentyuk, "Development of heat detector based on fuzzy logic using Arduino board microcontroller," in *Proceedings of the 17th International Conference on the Experience of Designing and Application of CAD Systems (CADSM)*, Jaroslaw, Poland, 2023, pp. 1–5, doi: 10.1109/CADSM58174.2023.10076536.
[5] A. V. Fomin, A. I. Glushchenko, and A. A. Ugarov, "Application of fuzzy logic to develop predictive controller," in *Proceedings of the 1st International Conference on Control Systems, Mathematical Modelling, Automation and Energy Efficiency (SUMMA)*, Lipetsk, Russia, 2019, pp. 315–319, doi: 10.1109/SUMMA48161.2019.8947573.
[6] S. K. Pattnayak, S. Choudhury, N. Nayak, D. P. Bagarty, and M. Biswabandhya, "Maximum power tracking and harmonic reduction on grid PV system using chaotic gravitational search algorithm based MPPT controller," in *Proceedings of the International Conference on Computational Intelligence for Smart Power System and Sustainable Energy (CISPSSE)*, Keonjhar, India, 2020, pp. 1–6, doi: 10.1109/CISPSSE49931.2020.9212268.
[7] M. Dabboussi, A. Hmidet, and O. Boubaker, "An efficient fuzzy logic MPPT control approach for solar PV system: A comparative analysis with the conventional perturb and observe technique," in *Proceedings of the 6th IEEE International Energy Conference (ENERGYCon)*, Gammarth, Tunisia, 2020, pp. 366–371, doi: 10.1109/ENERGYCon48941.2020.9236503.
[8] N. Cherigui, A. Chemidi, A. Tahour, M. Horch, W. M. Kacemi, and F. Saidi, "An advanced MPPT strategy: Hybrid sliding mode control with adaptive gain-based optimization via fuzzy logic techniques for stand-alone PV system," in *Proceedings of the 3rd International Conference on Electronics, Energy and Measurement (IC2EM)*, Algiers, Algeria, 2025, pp. 1–6, doi: 10.1109/IC2EM63689.2025.11101061.
[9] R. Sankar, S. Velladurai, R. Rajarajan, and J. A. Thulasi, "Maximum power extraction in PV system using fuzzy logic and dual MPPT control," in *Proceedings of the International Conference on Energy, Communication, Data Analytics and Soft Computing (ICECDS)*, Chennai, India, 2017, pp. 3764–3769, doi: 10.1109/ICECDS.2017.8390168.
[10] R. K. Rai and O. P. Rahi, "Fuzzy logic based control technique using MPPT for solar PV system," in *Proceedings of the First International Conference on Electrical, Electronics, Information and Communication Technologies (ICEEICT)*, Trichy, India, 2022, pp. 1–5, doi: 10.1109/ICEEICT53079.2022.9768650.
[11] J. John, A. Yoonus, F. Shijad, M. A. Mm, A. Thasneem, and L. Arun, "Isolated PV system with fuzzy logic based MPPT controller and battery management system," in *Proceedings of the 5th International Conference on Electrical, Electronics, Communication, Computer Technologies and Optimization Techniques (ICEECCOT)*, Mysuru, India, 2021, pp. 194–199, doi: 10.1109/ICEECCOT52851.2021.9707930.
[12] B. Pooja, S. Rajanna, N. L. Varaprasad, M. Ramesh, G. R. Sowmya, and S. R. Rakshitha, "Design of a battery charge controller through MPPT based solar photovoltaic system," in *Proceedings of the Fourth International Conference on Emerging Research in Electronics, Computer Science and Technology (ICERECT)*, Mandya, India, 2022, pp. 1–6, doi: 10.1109/ICERECT56837.2022.10060581.
[13] L. Matindife and Z. Wang, "Fuzzy logic based solar panel and battery control system design," in *Proceedings of the International Conference on Machine Learning and Cybernetics (ICMLC)*, Ningbo, China, 2017, pp. 98–104, doi: 10.1109/ICMLC.2017.8107749.
[14] R. S. P. H. Dinata, H. Suryoatmojo, and Suwito, "Fuzzy logic supervisory for multi-input step-up DC-DC Converter," in *2024 International Seminar on Intelligent Technology and Its Applications (ISITIA)*, Mataram, Indonesia, 2024, pp. 554-559, doi: 10.1109/ISITIA63062.2024.10668324.
[15] P. Deori, R. Bhuyan, and A. Ahmad, "Improved control scheme for grid connected solar PV system with fuzzy MPPT," in *Proceedings of the IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES)*, Jaipur, India, 2022, pp. 1–6, doi: 10.1109/PEDES56012.2022.10080434.
[16] Prashant and A. Rawat, "Analysis of solar PV system incorporating MPPT and performance examination of P&O and fuzzy logic methodology," in *Proceedings of the International Conference on Control, Computing, Communication and Materials (ICCCCM)*, Prayagraj, India, 2024, pp. 147–152, doi: 10.1109/ICCCCM61016.2024.11039903.
[17] S. A. Khan and M. I. Hossain, "Design and implementation of microcontroller based fuzzy logic control for maximum power point tracking of a photovoltaic system," in *Proceedings of the International Conference on Electrical and Computer Engineering (ICECE)*, 2010, pp. 322–325, doi: 10.1109/ICELCE.2010.5700693.
[18] C. B. Prasad, S. K. Sonam, B. R. G. Reddy, and P. Harika, "A fuzzy logic based MPPT method for solar power generation," in *Proceedings of the International Conference on Intelligent Computing and Control Systems (ICICCS)*, 2017, pp. 1182–1186, doi: 10.1109/ICCONS.2017.8250654.
[19] M. P. Raj and A. M. Joshua, "Design, implementation and performance analysis of a LabVIEW based fuzzy logic MPPT controller for stand-alone PV systems," in *Proceedings of the IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI)*, 2017, pp. 1012–1017, doi: 10.1109/ICPCSI.2017.8391863.
[20] Y. Lozanov, S. Tzvetkova, and A. Petleshkov, "Simulation Model For Evaluation Of Power Quality Indicators In Industrial Power Supply Systems With Grid-Tied PV System," in *2023 18th Conference on Electrical Machines, Drives and Power Systems (ELMA)*, Varna, Bulgaria, 2023, pp. 1-4, doi: 10.1109/ELMA58392.2023.10202315.
[21] J. I. Corcau and L. Dinca, "Modeling and analysis of a fuzzy type MPPT algorithm," in *Proceedings of the International Conference on Electrical Drives and Power Electronics (EDPE)*, 2019, pp. 230–234, doi: 10.1109/EDPE.2019.8883925.

[22] A. Roshan, P. Dwivedi, and H. Kumar, "Fuzzy based MPPT and energy management strategy," in *Proceedings of the IEEE Control and System Graduate Research Colloquium (ICSGRC)*, 2019, pp. 14–19, doi: 10.1109/ICSGRC.2019.8837080.
[23] W. Hayder, A. Abid, M. B. Hamed, and L. Sbita, "Intelligent MPPT algorithm for PV system based on fuzzy logic," in *Proceedings of the International Multi-Conference on Systems, Signals and Devices (SSD)*, 2020, pp. 239–243, doi: 10.1109/SSD49366.2020.9364195.
[24] M. Alsumiri, "Residual Incremental Conductance Based Nonparametric MPPT Control for Solar Photovoltaic Energy Conversion System," *IEEE Access*, vol. 7, pp. 87901-87906, 2019, doi: 10.1109/ACCESS.2019.2925687.
[25] M. P. Thakre and N. Kumar, "Evaluation and control perceptive of VSM-based multilevel PV-STATCOM for distributed energy system," *MAPAN*, vol. 36, pp. 561–578, 2021, doi: 10.1007/s12647-021-00481-x.

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