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P&O-Fuzzy logic controller designed for PV system with SEPIC converter

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Abstract

A novel maximum power point tracking (MPPT) technique is presented in this research, combining a single-ended primary inductor converter (SEPIC) with a Perturb and Observe algorithm fuzzy logic controller (P&O-FLC). This advanced controller builds upon the traditional perturb and observe method by incorporating rules into its search strategy, fuzzifying the process, and addressing its limitations. Compared to standard MPPT approaches, fuzzy logic controllers exhibit superior precision and rapid convergence to the maximum power point, maintaining effectiveness in both stable and fluctuating weather conditions. Simulation results demonstrate the performance of this innovative controller.

Keywords: *Perturb and Observe (P&O), Fuzzy-logic controller (FLC), Maximum-power-point-tracker (MPPT), Single-ended primary inductor converter (SEPIC), Photovoltaic (PV).*

1. Introduction

The non-renewable energy sources are rapidly running out, while the electricity demand is increasing daily. To solve this problem, efficient electric power generation from renewable energy sources is required [1]. Renewable energy is one of the forms of energy that society can rely on because It is unpolluted, pure, and has no limits. One type of power generation that uses renewable energy is the photovoltaic (PV) system [2]. To utilize less conventional energy, the PV system must subsequently be linked to the grid, either directly or via a backup battery bank. Since the power produced by PV systems depends on radiation and temperature change, the PV framework has destitute productivity [2].

DC-DC converters, such as Buck, Boost, and Buck-Boost types, play a crucial role in PV system control. The single- ended primary-inductor converter (SEPIC) stands out as a buck-boost DC-DC converter, offering output voltage adjustment based on duty cycle. SEPIC distinguishes itself from traditional buck-boost converters by providing a non-inverted

output and utilizing a coupling capacitor for input-output isolation [3]. Buck and Buck-Boost converters face significant drawbacks, losing half of the input power due to input current switching, which makes them unsuitable for maximum power transfer applications. Although the Boost converter maintains continuous input current, its output voltage consistently exceeds the input, potentially impeding maximum power point tracking (MPPT) when the maximum output voltage falls below the input [3].

This research introduces a fuzzy logic-enhanced Perturb and Observe (P&O) method for MPPT in standalone PV systems. The proposed approach builds upon the strengths of the P&O technique while mitigating its inherent weaknesses. By categorizing the output into five fuzzy subsets, the system enables ongoing adjustments to maximize power extraction from PV arrays. This strategy enhances PV module efficiency by consistently facilitating maximum power transfer.

2. Modeling of PV system

The field of photovoltaics encompasses the scientific principles and technological applications related to devices that convert sunlight directly into electricity using semiconductors with photovoltaic characteristics. Solar energy is transformed into DC electrical power through the use of photovoltaic cells [4]. These cells are commonly arranged into photovoltaic panels, which are composed of multiple cells linked in series (Ns) or parallel (Nsh) configurations. Each individual cell can be represented as a current source in parallel with a diode, as shown in Figure 1 [5].

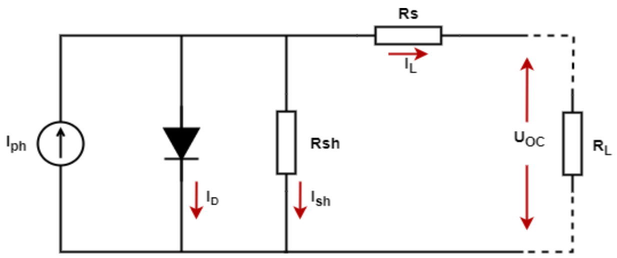

Figure 1: Circuit for a PV array.

The following equations provide the output current:

$$I = I_{ph} - I_D \quad (1)$$

$$I - I_{ph} - I_0 \left[\exp\left(\frac{q(V+R_S I)}{A k_B T}\right) - 1\right] - \frac{V+R_S I}{R_{sh}} \quad (2)$$

The shunt resistance (R_{sh}) is typically orders of magnitude larger than the series resistance (R_S) [6]. Therefore, it is common for the shunt and series resistances of a solar cell can be neglected to simplify the model. The resulting ideal voltage- current characteristic of the solar cell is given by equation (3).

3. Sepic converter

DC-DC converters are a central focus in power electronics research, with an emphasis on developing less complex designs that achieve higher efficiency [7]. A DC-to-DC converter utilizing SEPIC topology is introduced to ensure stable output voltage regulation. The SEPIC converter's components include a duty cycle switch S, a diode, two inductors (L1, L2), two capacitors (C1 and C2), and a load resistor, as depicted in Figure 2. As a type of DC-DC converter [8], SEPIC converters can generate output voltages that are lower than, higher than, or equal to the input voltage. Output voltage control is achieved by adjusting the duty cycle through modifications to the control transistor's conduction time. Another way to conceptualize a SEPIC converter is as a combination of a boost converter and a buck-boost converter in series. This configuration offers several advantages, such as a non-inverted output voltage (maintaining input polarity), improved energy transfer from input to output via the series capacitor (enhancing short-circuit current performance), and zero-quiescent power consumption. When switch "S" is turned off, the output voltage drops to 0V, accompanied by a substantial charge transient discharge [9].

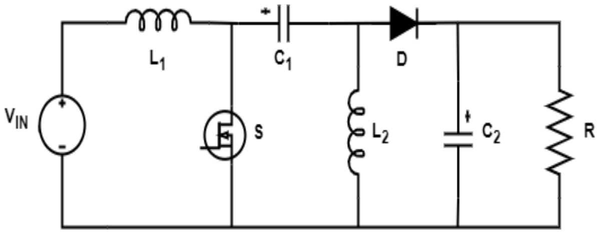

Figure 2: Simple circuit diagram of the SEPIC converter

In Figure 3, the operational states of the circuit during power switch activation and deactivation are demonstrated in subfigures (a) and (b), respectively. In Figure 3a, when the switch is in the "on" position, the input voltage source supplies current to the primary inductor, L1. Concurrently, the secondary inductor, L2, receives energy from the initial capacitor, C1, while the output capacitor, C2, supplies the required current to the load.

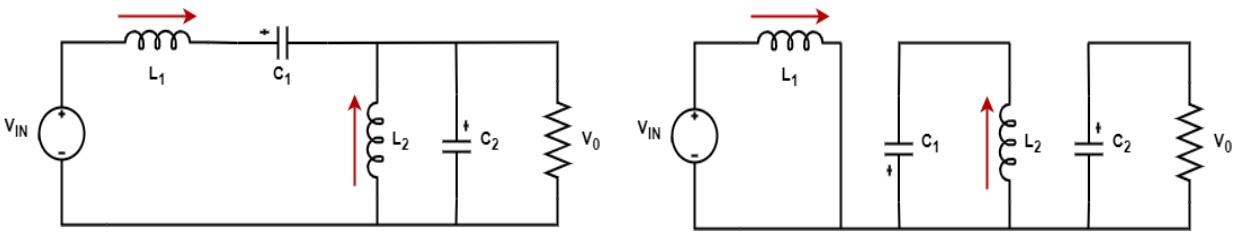

Figure 3.a: The switch turned on. **Figure 3.b:** The switch turned off.

Figure 3: Schematic representation of the SEPIC converter's circuit during switch on and off states.

Upon activation of the switch, the source initiates charging of the input inductor, while the primary capacitor concurrently charges the secondary inductor. During this interval, no energy is supplied to the load capacitor. Figure 3 illustrates the polarity orientation for the inductor currents and capacitor voltages. Once the power switch is deactivated, the energy stored within the inductor is redirected through the diode, supplying the load [10], as shown in Figure 3b. During this "off" phase, the secondary inductor is also connected to the load, and the output capacitor receives a current pulse, leading to increased noise levels relative to conventional buck converters.

The degree to which SEPIC converters adjust the output voltage is largely determined by the duty cycle and the circuit's parasitic components. For an ideal SEPIC converter, the output voltage can be represented as:

$$V_{out} = \frac{D}{1-D} V_{in} \qquad (3)$$

The power generated by the PV system is managed via a SEPIC converter, which adjusts the voltage up or down to meet the requirements at the load point. In this configuration, the SEPIC converter operates specifically in buck mode, reducing the voltage from the PV system as needed for the load.

4. Fuzzy logic control

In this MPPT algorithm based on fuzzy logic, the voltage and current at every time step (k) are measured to compute the active power. This active power was compared with the power at the preceding time step (k-1) to calculate the variation in power (ΔP (k)). Similarly, the voltage at step (k) is subtracted from the voltage at step (k-1) to determine the voltage error (ΔE (k)) [11]. The power error was divided by the voltage error to compute the overall error (E (k). This error is compared with the previous error to calculate the change in error (ΔE (k)). Both the error (E (k)) and the variation in error (ΔE (k)) are fed to the fuzzy logic controller. A flow chart of this MPPT algorithm with fuzzy logic is shown in Figure 4. It also uses the Mamdani type of inference technique, triangular A-type membership functions, and a 25-rule base for fuzzy logic control. It is the most preferred inference technique among researchers because it is simple to define fuzzy output sets and is more efficient than other inference methods [12]. The A-type or triangular membership function was chosen for the simplicity of partitioning the inputs into low- and high-membership types. In addition, triangular functions have been found to provide faster response times and lower overshoots than other types of membership functions [13]. A 25-rule base provides better performance in different applications [14][15].

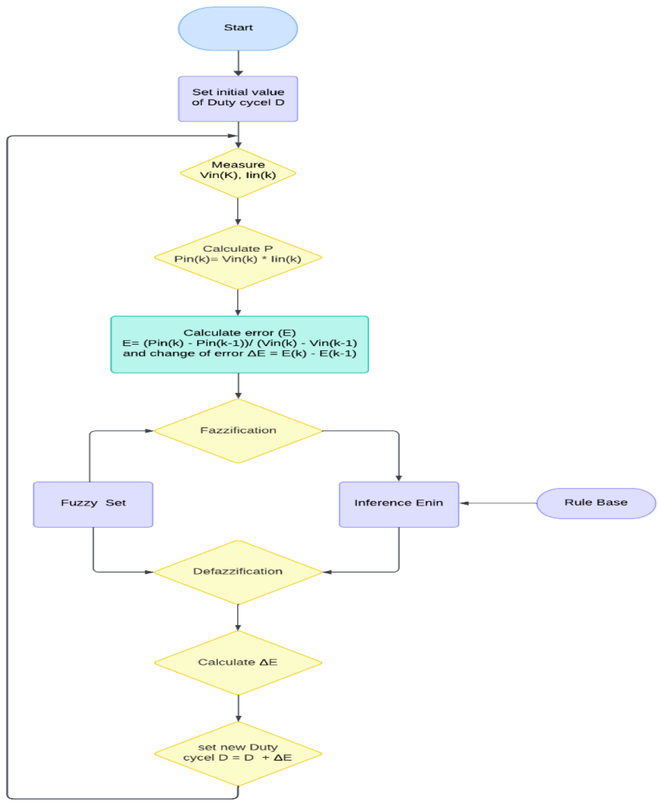

Figure 4: P&O-FLC MPPT flow chart.

Table 1 outlines the fuzzy logic rules used to attain the maximum power point (MPP) in the pulse width modulation (PWM) control of the push-pull converter. The membership functions associated with the input variables, ΔV (voltage change) and ΔP (power change), are depicted in Figure 5, while those for the output variable, ΔE (error change), are illustrated in Figure 6. The input membership functions are specified within the range [-1, 1], while the output membership functions are confined to the range [0, 1].

Table 1: Fuzzy logic guidelines for the push-pull converter.

ΔP / ΔV	**NB**		**ZE**	**PS**	**PB**
NB	PB	PB	PS	NS	NB
NS	PB	PS	ZE	NS	NB
ZE	PS	ZE	ZE	ZE	PS
PS	NS	NS	ZE	PS	PB
PB	NB	NS	PS	PB	PB

The abbreviations represent NB (negative big), NS (negative small), ZE (zero), PS (positive small), and PB (positive big).

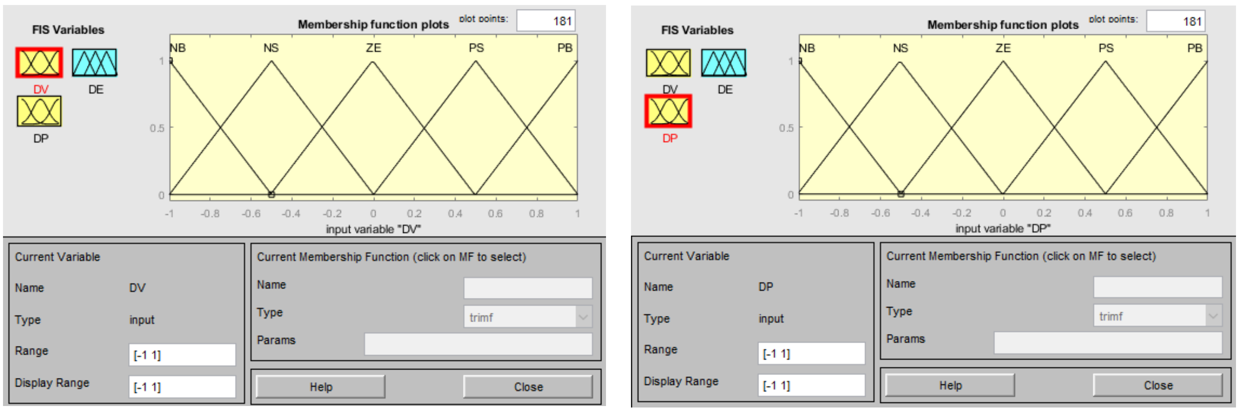

Figure 5: Membership for input variables.

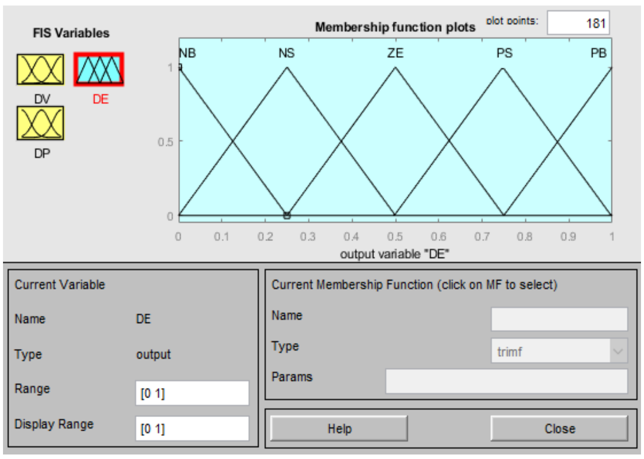

Figure 6: Membership for output variable.

5. Simulation results

The characteristics of the photovoltaic array that we use in this paper are given in Table 2.

Table 2: Electrical data of photovoltaic array.

Variable	Value
Maximum Power	P_{max} = 200 W
Open circuit voltage	V_{oc} = 36.1 V
Short circuit current	I_{sc} = 7.35A
Voltage at maximum power	V_{max} = 29 V
Current at maximum power	I_{max} = 6.9 A

Table 3: The SEPIC converter parameters.

Variable	Value
Switching frequency	20 KHz
Load resistance	R_{Load}= 4.2 Ω
Inductance L_1	L_1 = 3.6 mH
Inductance L_2	L_2 = 0.9 mH
Capacitor C_1	C_1 = 180 µF
Capacitor C_2	C_2 = 1000 µF

Figure 7 shows the implementation of P&O-FLC for the PV system under MATLAB/SIMULINK:

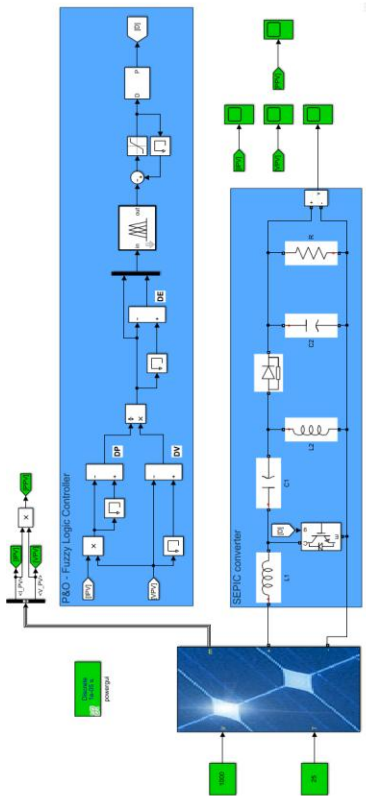

Figure 7: The implementation of P&O-FLC for the PV system under MATLAB/SIMULINK.

The results are provided under standard test conditions; G=1000 W/m2; T=25°C and it is shown in figure 8.

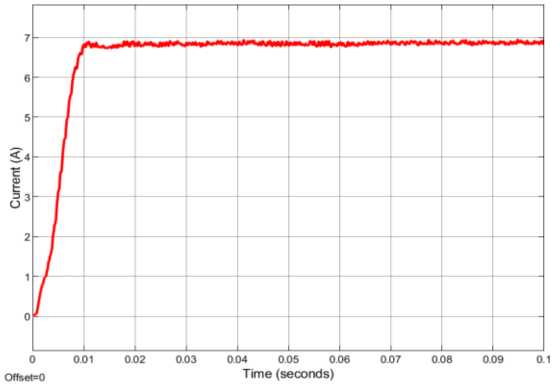

Figure 8.a: Current.

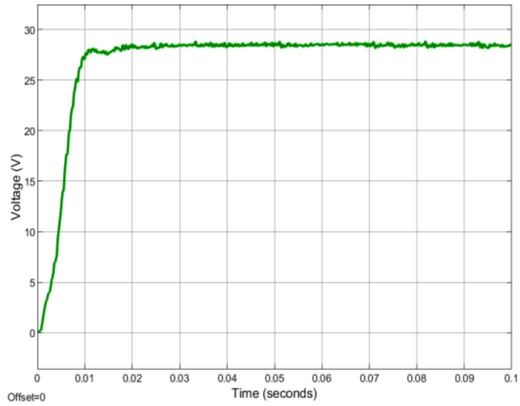

Figure 8.b: Voltage.

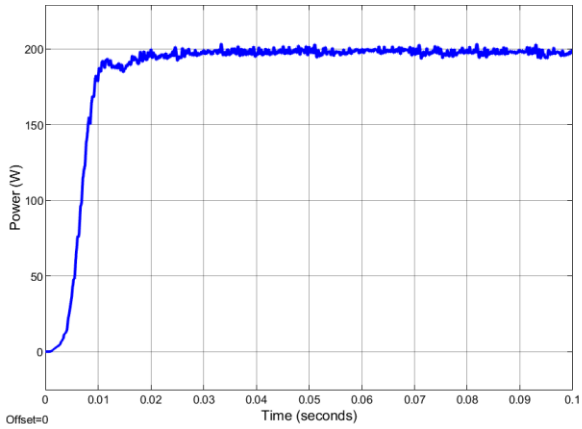

Figure 8.c: Power.

Figure 8: Current, voltage and power output results; at G=1000 W/m^2 and T=25°C.

The proposed controller fast-tracking the maximum power at 0.01 S, when the current I_{PV}= 6.83 A, the voltage V_{PV}= 28.56 V And the power P_{PV} = 198.7 W. This means this controller has an efficiency of 99.35%. Overall, using MPPT and fuzzy logic in a SEPIC converter for a PV system result in considerable performance gains Increased power output, higher efficiency, decreased ripple, enhanced transient response, and resilience are examples of these enhancements.

6. Conclusion

This paper presents the design of an off-grid photovoltaic (PV) system using a fuzzy logic-based maximum power point tracking (MPPT) controller combined with a SEPIC converter. Simulations were performed in MATLAB/Simulink under various weather conditions to assess the system's performance.

The fuzzy logic MPPT algorithm was shown to outperform conventional techniques, such as Perturb and Observe (P&O), by offering greater accuracy in tracking the maximum power point and minimizing fluctuations, even during rapid changes in irradiance. The flexible nature of fuzzy logic control allowed for smoother and faster responses to environmental shifts, ensuring more stable operation compared to traditional methods.

The overall results demonstrate that the fuzzy logic MPPT-controlled SEPIC converter can significantly improve energy yield and system reliability in varying conditions, showing its potential for use in off-grid solar energy systems.

References

1. Mahendran, G., and K. V. Kandaswamy. "Ant Colony Optimized Tuned DC-DC Converter." International Journal of Computer Applications (0975–8887) International Conference on Innovations In Intelligent Instrumentation, Optimization And Signal Processing ICIIIOSP. 2013.
2. Dunia, J., & Mwinyiwiwa, B. M. (2013). Performance comparison between ĆUK and SEPIC Converters for maximum power point tracking using incremental conductance technique in solar power applications. International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering, 7(12), 1638-1643.
3. Cirrincione, M., Pucci, M., & Vitale, G. (2011). Growing neural gas (GNG)-based maximum power point tracking for high-performance wind generator with an induction machine. IEEE Transactions on Industry Applications, 47(2), 861-872.
4. Abdulkadir, M., Samosir, A. S., & Yatim, A. H. M. (2013). Modeling and simulation of a solar photovoltaic system, its dynamics and transient characteristics in LABVIEW. International Journal of Power Electronics and Drive Systems, 3(2), 185.
5. Bouzeria, H., Fetha, C., Bahi, T., Abadlia, I., Layate, Z., & Lekhchine, S. (2015). Fuzzy logic space vector direct torque control of PMSM for photovoltaic water pumping system. Energy Procedia, 74, 760-771.
6. Chen, Y. M., Liu, Y. C., Hung, S. C., & Cheng, C. S. (2007). Multi-input inverter for grid-connected hybrid PV/wind power system. IEEE transactions on power electronics, 22(3), 1070-1077.
7. Ganesh, S., Janani, J., & Angel, G. B. (2014). A maximum power point tracker for PV panels using SEPIC converter. International Journal of Computer and Systems Engineering, 8(2), 356-361.
8. Vijayabalan, R., & Ravivarman, S. (2012). Z Source Inverter for Photovoltaic System with Fuzzy Logic Controller. International Journal of Power Electronics and Drive Systems, 2(4), 371.
9. Ramkumar, A., & Florence, S. V. S. (2015). Analysis of Single Phase AC-DC SEPIC Converter using Closed Loop Techniques. International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, 4(2).
10. Tadi, G. L. K. R., Ramamurthyraju, P., & Kumar, V. R. (2013). Analysis of SEPIC for PV-Applications using PI Controller and Current Mode Control. International Journal for Scientific Research e Development (IJSRD), 1(9), 1821-1824.
11. Li, J., & Wang, H. (2009, May). A novel stand-alone PV generation system based on variable step size INC MPPT and SVPWM control. In 2009 IEEE 6th International Power Electronics and Motion Control Conference (pp. 2155-2160). IEEE.
12. Wang, C. (2015). A study of membership functions on mamdani-type fuzzy inference system for industrial decision-making. Lehigh University.
13. Usta, M. A., Akyazi, Ö., & Altaş, İ. H. (2011, December). Design and performance of solar tracking system with fuzzy logic controller used different membership functions. In 2011 7th International Conference on Electrical and Electronics Engineering (ELECO) (pp. II-381). IEEE.

14. Mudi, R. K., & Pal, N. R. (1999). A robust self-tuning scheme for PI-and PD-type fuzzy controllers. IEEE Transactions on fuzzy systems, 7(1), 2-16.
15. Shehata, A., Metered, H., & Oraby, W. A. (2015). Vibration control of active vehicle suspension system using fuzzy logic controller. In Vibration Engineering and Technology of Machinery: Proceedings of VETOMAC X 2014, held at the University of Manchester, UK, September 9-11, 2014 (pp. 389-399). Springer International Publishing.