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AI controller for SEPIC converter of PV systems

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Abstract

This research presents a maximum power point tracking of traditional single-ended primary converter (SEPIC) with the aid of fuzzy logic controller (FLC) for regulating the voltage and perturbation and observation(P&O) algorithms for regulating the reference voltage and reaching the maximum power point tracking. This is a promising technique for the conventional SEPIC converter to achieve maximum power point tracking with much less error. Moreover, the method is simple, reliable, and understandable for photovoltaic systems.

Introduction

Due to various beneficial properties such as functioning [1], installation simplicity [2], and low maintenance cost[3], as well as the global availability of free and renewable resources associated with PV systems, photovoltaic (PV) energy has attracted global attention in recent years. For instance, Solar photovoltaic (PV) energy capacity installed in Canada increased at a nearly 150 percent annual pace from 2008 to 2011, reaching 495MW in 2011[4]. To attain the highest amount of output power of PV systems, the SEPIC converter and FLC are utilized.

The SEPIC converter offers several advantages over typical buck-boost converters. The SEPIC topology is based on the latter but with modifications to facilitate its drawbacks and improve performance [6][7]. To mention some advantages, the SEPIC converter's output is non-inverting, while the buck-boost converter's output is inverting. Also, the Sepic converter exhibits less voltage ripple at the output than the Buck-Boost [5]. MPP tracking is significantly more manageable in this SEPIC converter since the quantity of input current ripple is non-pulsating. Another significant advantage over buck-boost is that the semiconductor switching device in the SEPIC is tied to the ground, which implies it only requires low-side driving, which is very convenient because high-side driving has higher complexity and requires more components to implement. As a result, the SEPIC converter is highly more convenient in comparison to a typical buck-boost converter.

For MPPT applications in Solar PV systems, the aforementioned advantages are crucial. MPPT aims to achieve optimal current and voltage operation points in order to maximize the power output. Literature on the subject points out that voltage and current ripples can negatively affect the capabilities to find the optimal operation point because these alterations can deceive the control system in the wrong direction in the I-V curve [8].

The way all the phenomena associated with the power converters affect the MPPT performance will depend on the selected method. Artificial Intelligence MPPT is among the prevalent techniques [9]. Another technique is Perturb and Observe (P & O), which is a widely used method in solar system commercial products, as mentioned in [23]. Perturb and Observe, as the name implies, produce changes to the current or voltage and measure the power output; if the measured Power is increased, then the current or voltage keeps changing in the same direction until reaching the maximum point, which is where the power output starts to decrease. Hence the maximum Power is identified. On the other hand, if at the start of the algorithm, a descent in the power output is measured, the direction in which current or voltage is changed is consequently reversed [10]. It is clear that one of the main advantages of this method is its simplicity and intuitiveness. However, the P&O approach has the disadvantage that, in steady-state, the operating point varies in relation to the maximum power point [24]. The latter results in the waste of available energy, especially in atmospheric circumstances that are either constant or slowly changing. Also, the P&O method can be easily confused by rapidly changing atmospherical conditions. The voltage and current ripples produced by the switching behaviour of the power converters have a huge impact too on the malfunction of the P&O technique. The step size used for the algorithm can solve these drawbacks to some extent. In this work, a SEPIC converter model with a Fuzzy Logic controller is presented. The design was based on [20] and [21], suggesting that the fuzzy logic controller should be built with two inputs, actual PV current and PV voltage, and these parameters are converted to a fuzzy Set using the trapezoidal approach. The rules are used to determine the duty cycles for the converters based on the time-varying voltage and current as an input to the fuzzy rules. The unclear set value is converted to a crisp set using the center of gravity approach as a result. The signal is sent into a PWM generator to generate the pulses for the DC-DC converter [22].

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Proposed Model

The diagram of the conventional SEPIC converter with PI controller is shown in figure 1. The MPPT is implemented as a custom Matlab function. The selected Technique was the P&O method. The block receives the current and voltage output from the PV panels and an increment value. For this P&O scheme, the voltage is modified according to the established increment value, which in this model is set constant. Each time the voltage is modified, the output power is computed to compare to the previously measured output power. If the new measured Power is greater than the previous one, then voltages keep changing the same amount. Otherwise, the increment is applied with the opposite sign; that is if the new measures output power is lower then the increment direction is the opposite. Zero-order holds included in the model to account for the sampled nature of the process. The sample time dramatically influences the MPPT performance according to the literature as previously mentioned. The MPPT generates a voltage setpoint for the PI controller, this set point is intended to maximize the Power gathered from the PV panels. The PI task is to compute the duty cycle required to drive the SEPIC output voltage the close as possible to the voltage reference commanded by the MPPT.

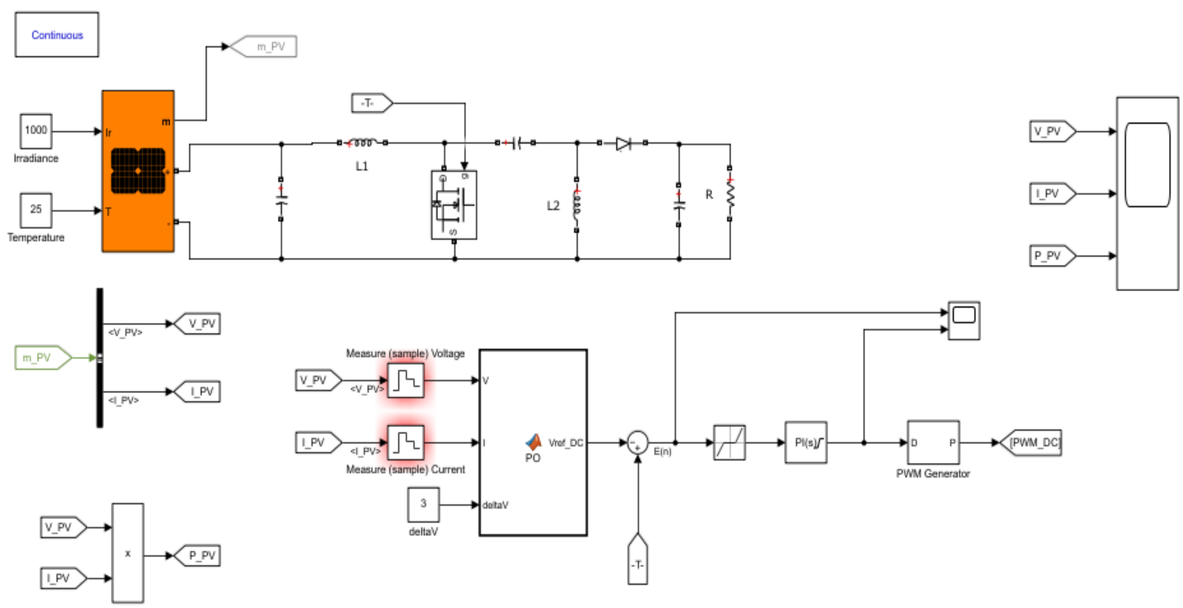

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Figure 1. Simulink model with SEPIC converter and MPPT - PI controller.

Figure 2 it is shown a control scheme that uses FLC instead of PI controller. The output of the SEPIC converter is compared to the reference voltage and P&O. Afterwards, the results will be compared. The fuzzy logic controller is responsible of adjusting the duty cycle in order to ensure zero steady-state error ay the output, which leads to reaching the maximum powerpoint.

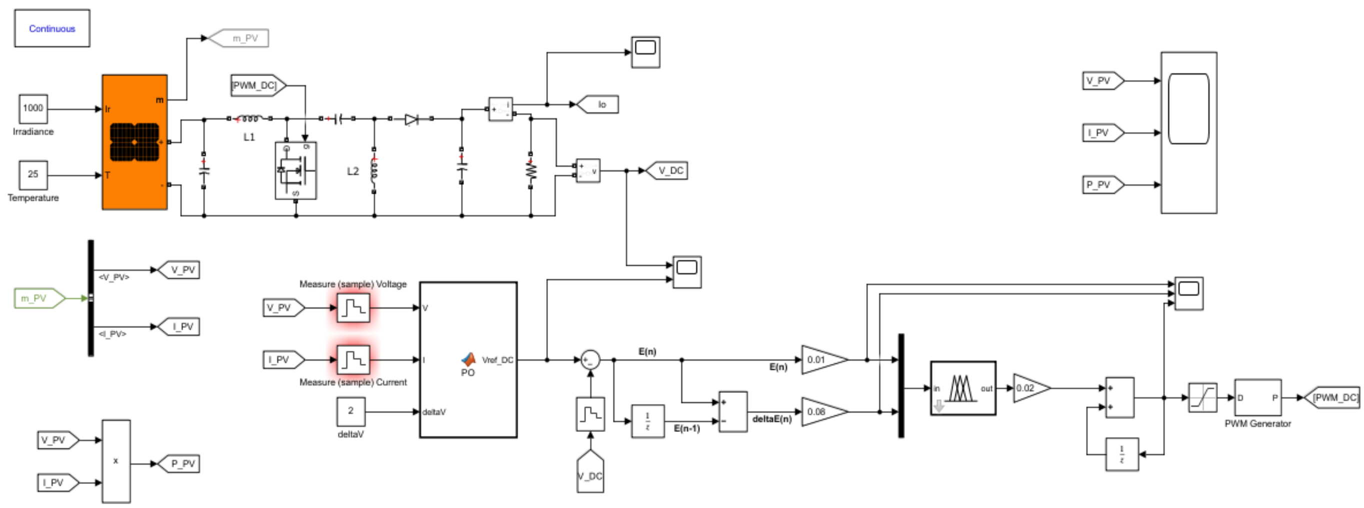

Figure 2. Simulink model with the Proposed MPPT with Fuzzy controller for the SEPIC converter.

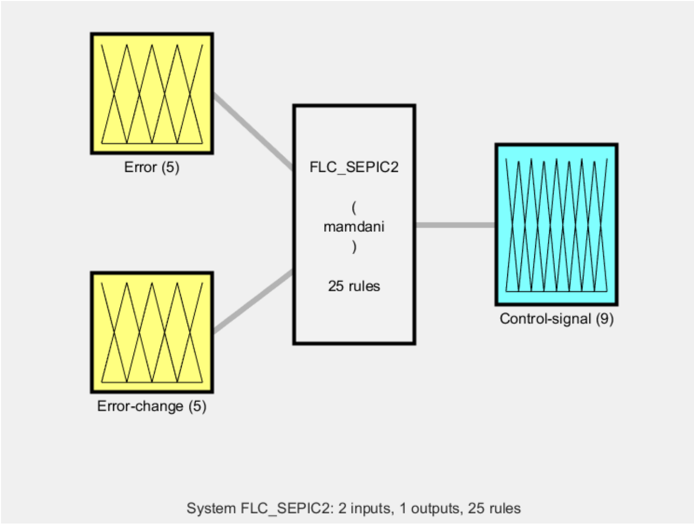

Figure 3. implemented Fuzzy logic controller.

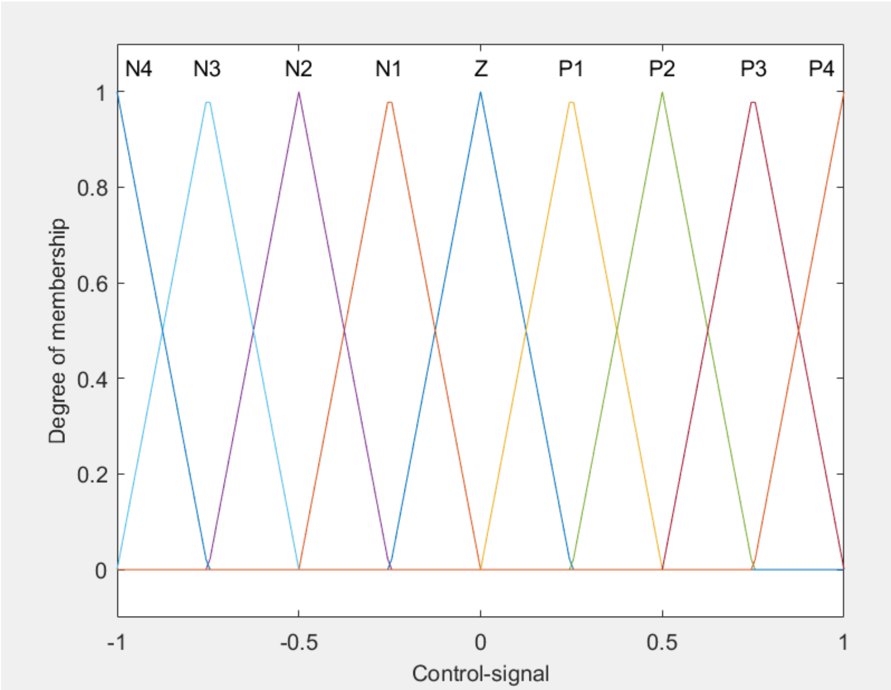

Figure 4. output membership functions.

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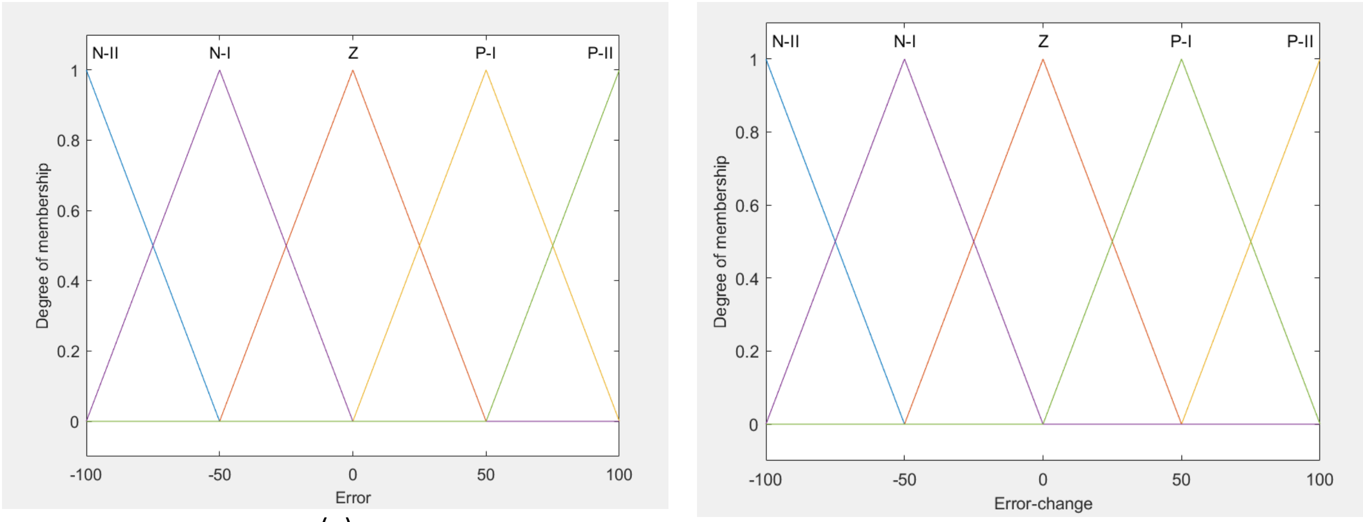

Figure 5. (a) Error Membership function. (b) Error derivative membership function.

In the FLC design, the primary control variables should be identified, as well as the sets that explain the values of each language. The voltage error e(n) and the error change ∆e are the FLC's input variables. The duty cycle of d(n) of the PWM signal, which governs the output voltage, is the FLC's output. The membership functions of the SEPIC-side FLCs' inputs and outputs are triangular membership functions as depicted in figures 4 and 5. This function was chosen to make computations easier. Each linguistic variable is described by a five-term fuzzy set, which includes negative large (N-II), negative small (N-I), zero (Z), positive small (P-I), and positive big (P-II).

Furthermore, as shown in, the output variables' membership functions are nine-term fuzzy sets with classic triangular shapes, namely, negative very big (N4), negative big (N3), negative small (N2), negative very small (N1), zero (Z), positive very small (P1), positive small (P2), positive big (P3), and positive very big (P4) (P4). The suggested FLC employs the Mamdani fuzzy inference approach. By fuzzifying the rules, the new controller improved the previous search strategy and fuzzy has presented an accurate and rapid convergence to a maximum PowerPoint in comparison with conventional logic trackers in both steady-state and variable weather conditions. When compared to conventional methods, The proposed FLC technique can deliver faster response and fewer errors, according to P&O tracker data oscillations in the vicinity of the steady-state.

The block adjusts its duty cycle in response to the control signal, configuring feedback from the output signal, which is expressed in voltage, current, and Power, to obtain the reference signal, which is unpredictably variable and adapts to the maximum Power achieved by duty cycle variations. In the case of a grid-connected system, a full load state, or battery charging in the case of a standalone system, the maximum power point can be reached. If, on the other hand, the load is excessive, Membership functions input and outputs of FLC of this method. To simulate the new reference signal coming from the MPPT, the fuzzy controller is applied to the SEPIC converter. The SEPIC converter switch's new duty cycle (k) has been changed. A formula (1) depicts the relationship between the current and prior responsibilities, i.e., cycles. As a result, the proposed FLC-based MPPT strategy for the SEPIC converter may be a viable option.

Results

Figure 6 presents the simulated SEPIC output voltage and the MPPT voltage reference. In this simulation, the irradiance and temperature were set constant. It can be seen that the desired operation point is achieved successfully. Also is noticeable that the P&O scheme is producing an oscillation since the algorithm is constantly searching for a maxima point for the power output. Once this maximum is found, it is clear that any increment in the positive or negative direction will produce a decrease in the power output. The latter results in an oscillation. This agrees with the results found in the literature addressing the P&O technique.

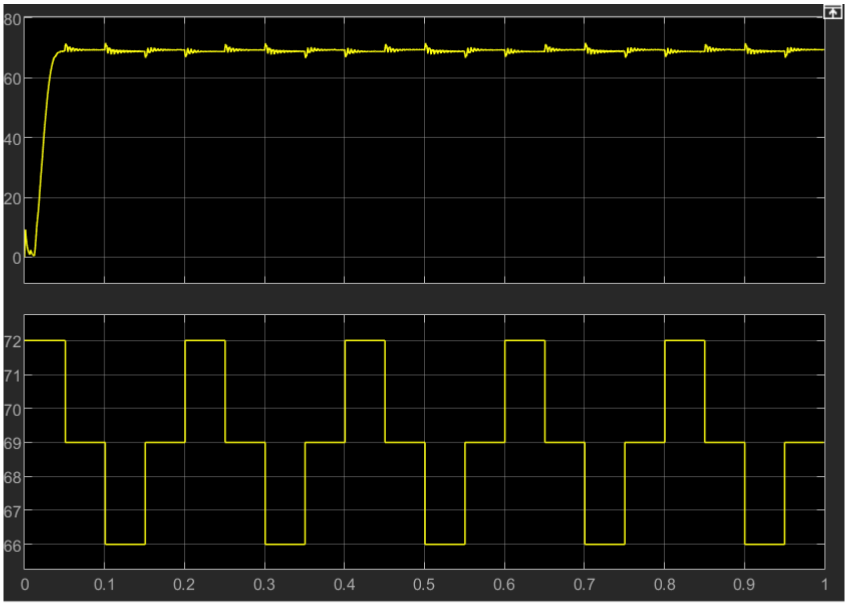

Figure 6. top signal is SEPIC output voltage. The bottom signal is the voltage reference commanded by the MPPT P&O block. Starting point near the maximum Power.

The previous result was obtained with a starting point near the optimum. Figure 7 shows what happens when the starting point is not near enough to the optimal powerpoint. It is evident that oscillations are more prevalent. It was also observed for different MPPT parameters such as the sampling time and the step increment that there are cases in which even instability occurs.

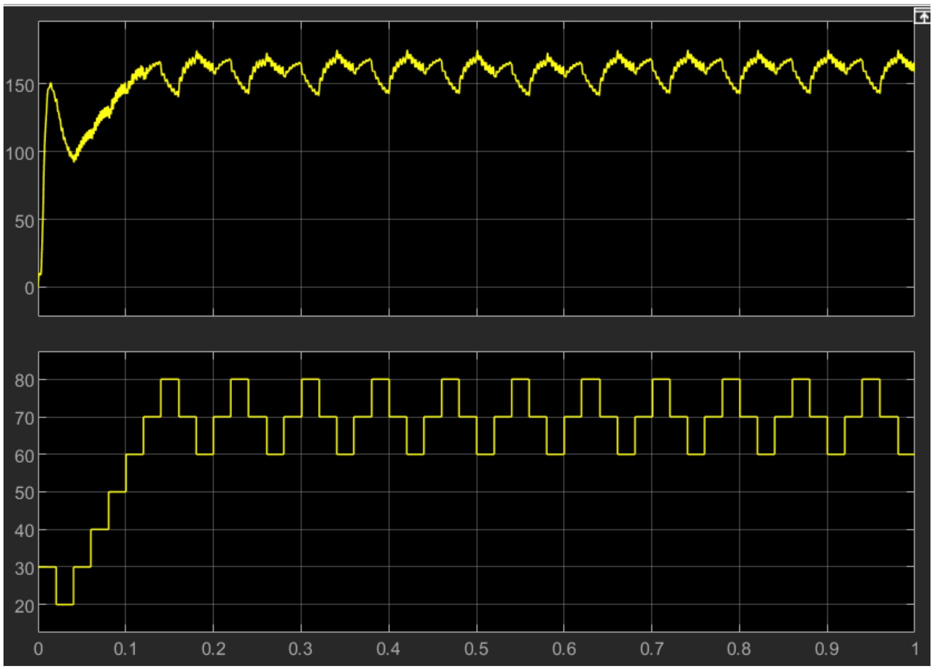

Figure 7. Figure 6. top signal is SEPIC output voltage. The bottom signal is the voltage reference commanded by the MPPT P&O block. The starting point is further away from maximum Power.

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As can be seen in figure 8, once the maximum power point is found, the system behavior is smother than in the PI controller case.

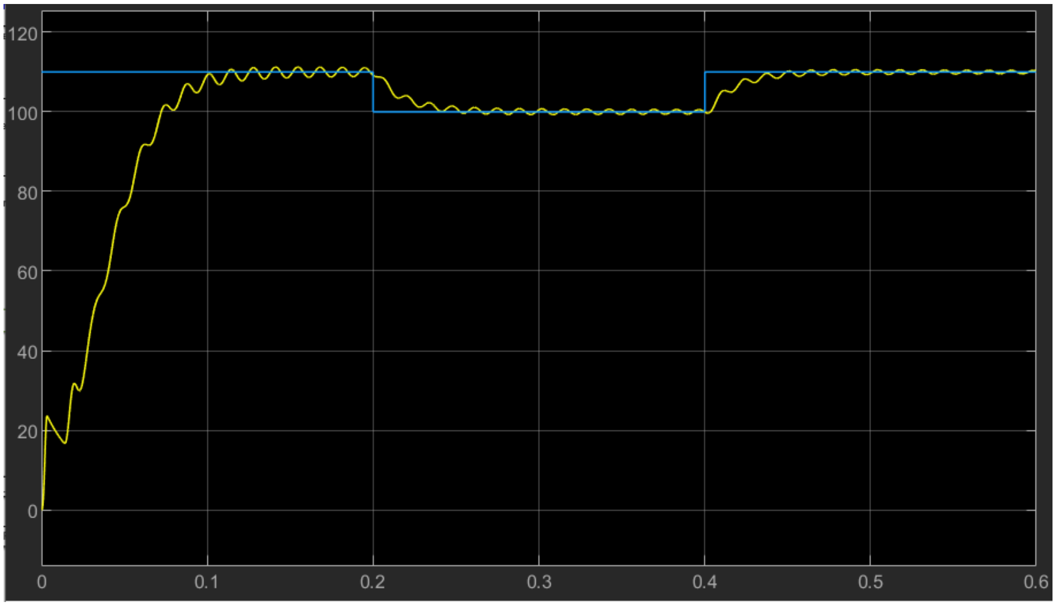

Figure 8. Output voltage yellow color. MPPT reference voltage blue color.

In both cases, oscillations are observed, but the fuzzy controller scheme has more potential to improve the performance of the system. Simulation results pointed out that the step increment and the sampling time configured in the MPPT can have a critical impact on systems instability in conjunction with the controller closed-loop gain. If both parameters are not properly set, the system performance could be disastrous.

Conclusions

The proposed Technique shows the capabilities of SEPIC converters. According to the simulation results, the suggested MPPT scheme is capable of tracking the global maximum power point with the aid of a fuzzy logic controller and P&O algorithm. Also, it was observed that most fuzzy-based MPPT algorithms have some drawbacks. If proper parameters are not set, unwanted oscillations and even instability can occur. It can be concluded that a combination of FLC and P&O algorithms is more applicable than previous techniques for MPPT systems. The simulation results also suggest that some studies to extend fuzzy control to other parameters like the step descend value in P&O scheme should be conducted.

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