

# Fuzzy-Logic-Controller-Based SEPIC Converter for MPPT in Standalone PV systems

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**Abstract** - *This paper presents a fuzzy controller (FC)-based single-ended primary-inductor converter (SEPIC) for maximum power point tracking (MPPT) operation of a photovoltaic (PV) system along with battery. The FLC proposed scheme uses the convergent distribution of the membership function. The fuzzy controller for the SEPIC MPPT scheme shows the voltage without any changes in different load conditions at the inverter output (load) side. The behaviour of the converter is tested in simulation at different operating conditions. The load is fed from the battery storage continuously with constant voltage. The battery will be charge with the help of PV module and the SEPIC converter, which is controlled by FLC-based MPPT. The proposed FLC-based MPPT with battery will supply more power to the load than the without battery system.*

**Key Words:** *SEPIC converter , fuzzy controller, photovoltaic(PV) modules, battery ,inverter.*

## I.INTRODUCTION

The single-ended primary inductor converter (SEPIC) acts as a buck-boost dc-dc converter, where it changes its output voltage according to its duty cycle. The selection of a proper dc-dc converter plays an important role for maximum power point tracking (MPPT) operation. Due to its output gain flexibility. Among known converters, the SEPIC, conventional buck-boost, and Cuk converters have the ability to step up and step down the input voltage. Hence, this converter can transfer energy for all irradiation levels. Another desirable feature is continuous output current, which allows converter output parallel connection, or conversion to a voltage source with minimal capacitance. The buck or boost converters are not preferable, due to the lack of output voltage flexibility. The SEPIC is chosen because the output voltage can be higher or lower than the input voltage. Also the input and output voltages are dc isolated. The isolation is provided by the

series capacitor  $c$ , which blocks the dc from the supply side to the output side[1]. An auxiliary switch and a clamp capacitor are connected. A coupled inductor and an auxiliary inductor are utilized to obtain ripple-free input current. The voltage multiplier technique and active clamp technique are applied to the conventional SEPIC converter to increase the voltage gain, reduce the voltage stresses of the power switches and diode. Moreover, by utilizing the resonance between the resonant inductor and the capacitor in the voltage multiplier circuit, the zero-current-switching operation of the output diode is achieved and its reverse-recovery loss is significantly reduced. Both the SEPIC and the Cuk converter provide the choice to have either higher or lower output voltage compared to the input voltage. The MPPT algorithm represents optimal load for PV array, producing opportune voltage for the load. SEPIC converters can have a low input current ripple, which is one of the advantages of SEPIC converters. However, a bulk inductor should be used to minimize the current ripple. Input current ripple becomes one of important requirements due to the wide use of low voltage sources such as batteries, super capacitors, and fuel cells. The PV panel yields exponential curves for current and **voltage, where the maximum power occurs at the curve's mutual knee.** The applied MPPT uses a type of control and logic to look for the knee, which in turn allows the SEPIC converter to extract the maximum power from the PV array. The tracking method used, i.e., perturb and observe (P&O). A tracking method based on parabolic function is proposed to perform the photovoltaic maximum power point tracking. With the proposed method, the maximum power calculation is made from a parabolic convex function. Then a systematic scheme is developed to adjust the concavity and optimal region of the approximate parabola for ensuring the iterative convergence of the proposed method. In order to confirm the effectiveness of this proposed design, the approach has been applied to investigate different atmospheric scenarios. Among different intelligent controllers, fuzzy logic is the simplest to integrate with the system. Recently, the fuzzy logic controller (FLC) has received an increasing attention to researchers for converter control, motor drives, and other

process control because it provides better responses than other conventional controllers. The imprecision of the weather variations that can be reflected by PV arrays can be addressed accurately using a fuzzy controller. In order to take the advantages of the fuzzy logic algorithm, the MPPT algorithm is integrated with the FLC so that the overall control system can always provide maximum power transfer from the PV array to the inverter side, in spite of the unpredictable weather conditions.

## II. PROPOSED SYSTEM

In this paper, the voltage level increases or decreases depending on the maximum power. Furthermore, the controller changes the voltage level by changing the duty cycle of the pulsewidth-modulated (PWM) signal, which tracks the reference signal. A sinusoidal reference signal is compared with the output signal to produce a supposedly zero error signal. Another reference signal is used to compare the SEPIC's output, to achieve the maximum power. This reference signal is adaptive, changing its shape according to weather conditions.

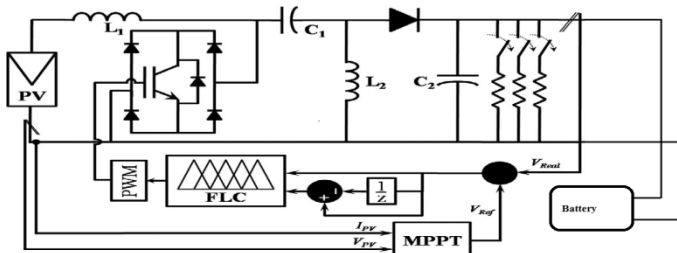


Fig. 1. Circuit diagram of the SEPIC converter for the FLC-based MPPT with battery scheme.

Fig. 1 is the circuit diagram of the SEPIC dc-dc converter together with the MPPT and the fuzzy controller with battery. The design of the fuzzy controller was done using Mamdani's method for the converter. The maximum power point can be achieved in case of a grid-connected system, a full-load condition, or using battery charging in case of a standalone system. However, if the load need is lower than PV capacity, the PV voltage will move right in the PV curve, achieving the opportune power. This case happens even if the batteries of the standalone system are full and the load is lower than PV power. In grid-connected systems, the load is always there due to the huge number of clients. Therefore, the maximum power point can always be achieved subject to the load need.

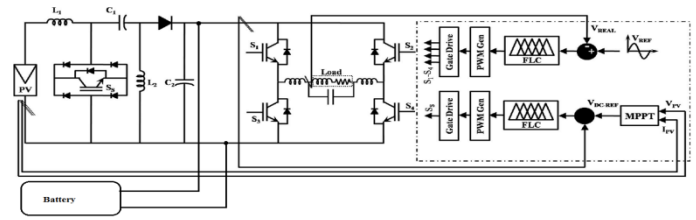


Fig:2 overall control scheme for the proposed FLC based MPPT scheme for the SEPIC converter with battery.

## III. FLC ALGORITHM

In FLC design, one should identify the main control variables and determine the sets that describe the values of each linguistic variable. The input variables of the FLC are the output voltage error  $e(n)$  and the change of this error  $e'(n)$ . The output of the FLC is the duty cycle of  $d(n)$  of the PWM signal, which regulates the output voltage.

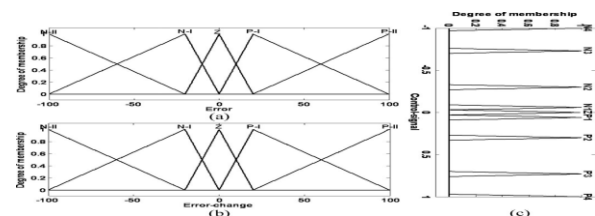


Fig. 3. Unsymmetrical focused membership function of the proposed FLC: (a)  $e(n)$ , (b)  $e'(n)$ , and (c)  $d(n)$ .

Fig.3 show the membership functions of the inputs and the outputs of the SEPIC-side FLCs. The triangular membership functions are used for the FLC for easier computation. A five-term fuzzy set, i.e., negative big (N-II), negative small (N-I), zero (Z), positive small (P-I), and positive big (P-II), is defined to describe each linguistic variable.

TABLE-I  
 FUZZY RULE-BASED MATRIX

e'/e	N-II	N-I	Z	P-I	P-II
N-II	Z4	Z4	Z4	Z3	Z
N-I	Z4	Z2	Z1	Z3	P3
Z	Z4	Z1	Z	P1	P4
P-I	Z3	Z	P1	P2	P4
P-II	Z	P3	P3	P3	P4

The fuzzy rules of the proposed PV SEPIC dc–dc converter can be represented in a symmetric form, as shown in Table I. Moreover, as in Fig.5, the membership functions of the output variables are nine term fuzzy sets with classical triangular shapes, i.e., 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). The Mamdani fuzzy inference method is used for the proposed FLC, where the maximum of minimum composition technique is used for the inference and the center-of-gravity method is used for the defuzzification process. Fig. 3 illustrates a focused membership function, where the sets go toward zero. the membership functions in Fig. 3 are guaranteed to produce the stable output signal. The design of the focused membership function values depends on the nature of the signal.

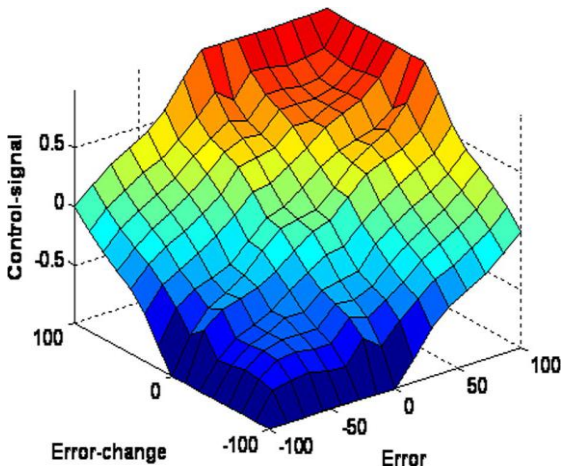


Fig. 4. Three-dimensional surface corresponding to the memberships in Fig. 3 and the rules in Table I.

The control signal value is confined between -1 and 1, owing to the PWM carrier wave. The input signal values are between -100 and 100 because of the error signal, which is resultant from the difference between the output signal and the desired reference signal. In addition, most of error values are centered from -20 to 20. The sharpness of the control signal is very essential for minimizing the error signal to zero in short time; wherefore, the pulse membership function is used to configure the control signal fuzzy sets. The FLC performance changes with unsymmetrical distribution of membership functions, where both convergent and divergent types of asymmetry will be considered with varying degrees of the unsymmetrical membership functions.

#### IV. PROPOSED MPPT-BASED SEPIC CONVERTER

The fuzzy controller is applied to the SEPIC converter to mimic the new reference signal coming from the MPPT. The new duty cycle  $\delta(k)$  of the SEPIC converter switch was adjusted either by adding or by subtracting the previous duty cycle  $\delta(k-1)$  with the **duty cycle's perturbation step size**. Equation (1) presents the relation between the present and previous duty cycles, i.e.,

$$\delta(k) = \delta(k-1) \pm \Delta\delta \quad (1)$$

where  $\Delta\delta$  is the change in duty cycle, resulting from the change of reference signal. The MPPT control technique is applied to achieve a new reference voltage for the fuzzy controller, which changes the duty cycle of the PWM signal for the SEPIC converter. The P&O algorithm has a simple structure and requires few parameters (i.e., power and voltage); that is why it is extensively used in many MPPT systems.

The P&O method perturbs the duty cycle and compares instantaneous power with past power. Based on this comparison, the PV voltage determines the direction of the next perturbation. P&O shows that, if the power slope increases and the voltage slope increases also, the reference voltage will increase; otherwise, it will decrease. The drawback of most of the fuzzy-based MPPT algorithms is that the tracking point is located away from the maximum power point when the weather conditions change. However, a drawback of P&O technique is that, at steady state, the operating point oscillates around the maximum power point giving rise to the waste of available energy, particularly in cases of constant or slowly varying atmospheric conditions. This can be solved by decreasing the step size of perturbation.

The step size of the P&O method affects two parameters: accuracy and speed. Accuracy increases when the step size decreases. However, accuracy leads to slow response when the environmental conditions change rapidly. Step sizes should, thus, be chosen well to achieve high speed and accuracy. The MPPT converter were done using MATLAB/Simulink. The first simulation used the characteristic equations of the PV array, whereas the second simulation used the solar-panel module given in Simulink. The MPPT algorithm was built via (.m) file and linked with Simulink. The SEPIC circuit was built via Sim Power toolbox.

Fig. 5 shows the curves for power versus voltage, at 25 °C and 50 °C, for radiation variations, from 250 W/m<sup>2</sup> to 1000 W/m<sup>2</sup>. For simulation purposes, the PV panel values and the number of PV arrays were taken depending on the experimental setup, The reference voltage signal, tracking the

maximum power, is shown in Fig. 6. The relation between Figs. 5 and 6 can now easily be determined. Hence, it is clearly noted that the maximum power occurs around 330 V.

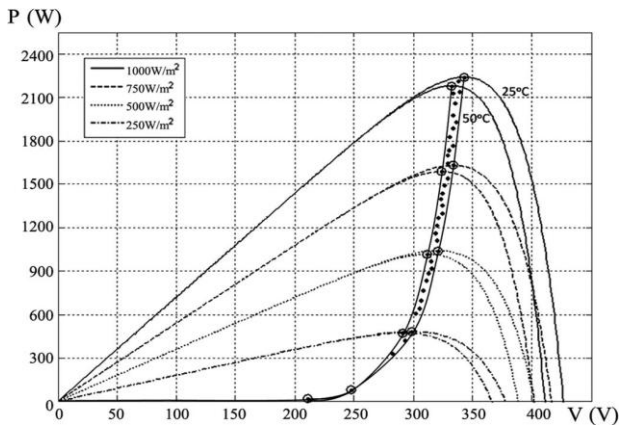


Fig. 5. Power-voltage (P-V) relation for the prescribed PV array.

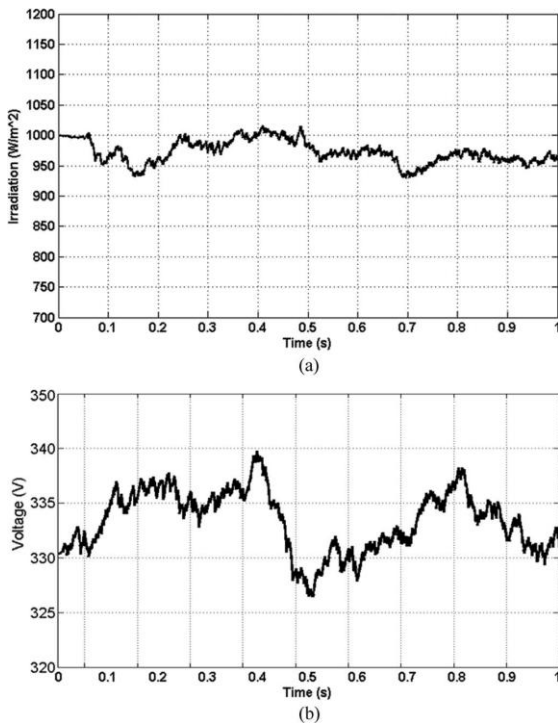


Fig. 6. (a) Irradiation (W/m<sup>2</sup>). (b) Reference voltage tracks the maximum power.

## V. EXPERIMENT IMPLEMENTATION

The module rated voltage is 17.3 V, as detailed in Table II. An array of 19 series solar modules was setup to generate 330-V dc voltage. Then, the PV array was connected to the SEPIC converter.

TABLE-II

parameters	value
maximum power	125W
warranted power	118.8W
rated current	7.23A
rated voltage	17.3V
short circuit current	7.9A
open circuit voltage	21.8V

Two 5-mH inductors are chosen to operate the converter in continuous conduction mode. The values of the input capacitor  $C_1$  and the output capacitor  $C_2$  are 470  $\mu\text{F}$  and 2200  $\mu\text{F}$ , respectively. The duty cycle changes for closed loop control under variable load conditions. To guarantee that the converter works on continuous conduction mode and to prevent converter damage, the duty cycle has been limited between 0.35 and 0.85.

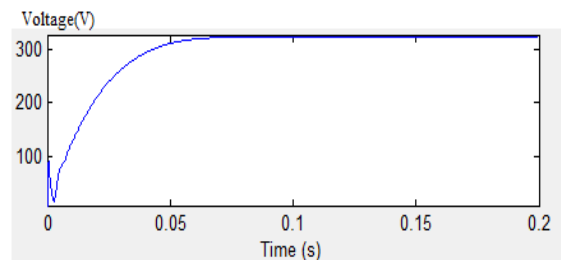


Fig. 7: Sepic output voltage wave form

## VI. SIMULATION RESULTS

Simulation was applied on MATLAB/Simulink to verify the practical implementation of the proposed SEPIC fuzzy controller for the single-phase inverter. Fig. 6 presents the reference signal for the SEPIC's output, where it tracks the maximum power. The output voltage of the proposed FLC based MPPT with battery at constant load condition are shown in Fig. 8. It is noticeable that the signals were not smooth; on the contrary, they carried a component of the maximum power between voltage and current. The voltage range changed from 320 to 340 V. The voltage signal in Fig. 8 is similar to the reference signal in Fig. 6.

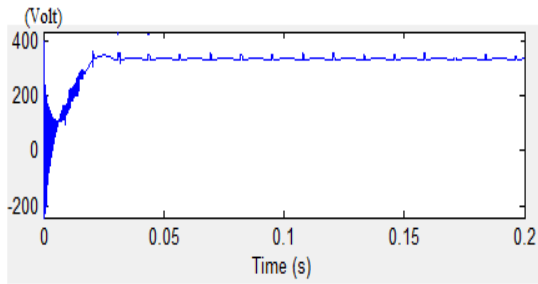


Fig.8: PV module voltage waveform

TABLE- III  
 INVERTER SPECIFICATIONS

parameters	values
S <sub>1</sub> -S <sub>4</sub>	IGBT,600V,GT50J32.
L <sub>A</sub>	3mH,14ASMP
C <sub>A</sub> ,C <sub>B</sub>	240μF,330V,AC
R <sub>L</sub>	50Ω,500W
voltage transducer	LEMLV25-P
current transducer	LEMLA25-NP
PV-output voltage	270-350V,DC
inverter output voltage	240Vrms
switching frequency(S1-S4)	20kHz
switching frequency(Ss)	50kHz

The total Simulink modal of the proposed system was as shown below

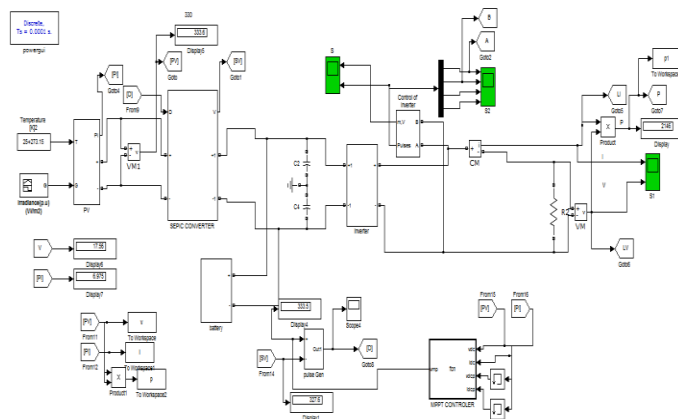


Fig.9: Simulink modal of the proposed system.

## VII. CONCLUSION

An FLC-based MPPT scheme for the SEPIC converter system for PV power applications has been presented. The performance of the proposed controller has been found better than that of the without battery system. The supply of voltage will be constant to the inverter input side through the battery. The battery will be charge with the help of SEPIC converter. The power usage of the load at the inverter output side was more with the battery system along the FLC based SEPIC with MPPT than the system without a battery. The proposed FLC-based MPPT scheme for the SEPIC converter could be a potential candidate for real-time PV inverter applications under variable load conditions.

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