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# Fuzzy Logic Controlled Interleaved Boost Converter for Battery Charging Applications

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**ABSTRACT** - This work presents an interleaved boost converter designed to enhance conversion efficiency, minimize output ripple, and reduce the need for passive components. The converter operates on a multi-phase principle, making it suitable for power factor correction applications. When applied to a solar energy system, the proposed converter enables improved power extraction with lower ripple losses, allowing the photovoltaic panel to operate closer to its maximum power capability. By implementing an energy-efficient current control strategy, an efficiency of approximately 95% is achieved. A fuzzy logic controller is employed to manage the switching operation of the converter, ensuring accurate control while limiting switching losses. The proposed system is mathematically modeled, and its performance is evaluated through simulation. MATLAB is used to carry out and analyze the simulation results.

**KEYWORDS:** Interleaved Boost Converter, Fuzzy Logic Controller, Voltage Regulation, EV applications

## I. INTRODUCTION

The rapid exhaustion of fossil fuel resources and the increasing impact of global warming have intensified the demand for environmentally friendly transportation solutions. Electric vehicles (EVs) have emerged as a practical and reliable response to stringent environmental regulations. Most EVs rely on high-capacity battery packs to supply the energy required for vehicle operation. In modern EV power systems, DC–DC converters play a crucial role by providing a regulated direct-current interface between the battery and the inverter stage. Among the various converter configurations, the two-phase interleaved step-up DC–DC converter (ISC) is particularly well suited for automotive, aerospace, industrial, and propulsion applications. Electric vehicles require large energy storage systems to deliver the necessary torque and speed, and converters such as buck, boost, and interleaved topologies are commonly employed to manage power flow efficiently. The use of interleaved structures enables battery packs to be made more compact while improving overall performance. Interleaving significantly reduces output voltage ripple, voltage stress, and power losses, while simultaneously enhancing voltage gain and conversion efficiency. To further improve system performance, fuzzy logic control (FLC) is applied due to its effectiveness in handling nonlinear and complex control problems. Unlike conventional control methods, FLC is based on expert knowledge and does not require an exact mathematical model of the system. This approach simplifies system design, improves voltage regulation, and lowers overall implementation costs. In the proposed system, fuzzy logic control is used to adjust the duty cycle of the ISC converter, thereby minimizing output voltage ripple and reducing power losses. This results in improved accuracy and higher efficiency. While the current structure of an interleaved converter is similar to that of a single-phase boost converter previously used in EVs, single-phase configurations are limited in their ability to supply sufficient voltage to the traction motor. By adopting a two-phase interleaved boost converter, the required motor voltage can be achieved while reducing the size and voltage rating of the battery pack, making the system more efficient and suitable for electric vehicle applications.

## II. METHODOLOGY

DC–DC converters are widely employed in photovoltaic (PV) systems to extract maximum available power from the solar panel. Conventional converters operate in both buck and boost modes, depending on the relationship between the panel voltage and the desired output level. When the panel voltage is lower than the reference value, the converter boosts the voltage, and when it exceeds the reference, the voltage is stepped down. However, frequent switching between these two modes can lead to reduced output stability and increased power losses. To overcome these limitations, an interleaved boost converter is adopted in the proposed approach. This configuration significantly reduces input current ripple while improving conversion efficiency for all operating conditions of the PV panel. By appropriately selecting the converter



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duty cycle, the panel voltage is raised to a constant and regulated level. A control mechanism is required to convert feedback signals into suitable gating pulses for the converter switches. In this system, a fuzzy logic controller is employed to determine the optimal duty cycle, eliminating the constraints of linear voltage control. Since the converter operates exclusively in boost mode, switching losses are minimized, resulting in improved overall efficiency. The block diagram of the proposed system is shown below.

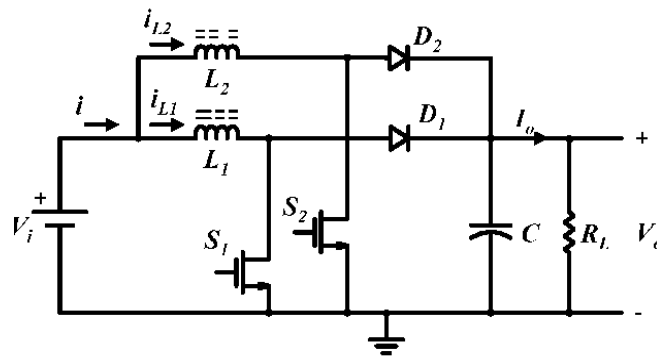


Fig 1. Proposed system Block diagram

In this configuration, the proposed interleaved boost converter is supplied by a DC voltage source. Based on the predefined switching logic, the switching unit generates appropriate gate pulses to control the converter switches. These gate signals ensure proper operation and coordination of the interleaved phases. The overall structure of the proposed interleaved boost converter is illustrated below.

#### A. Two-phase Interleaved Boost Converter

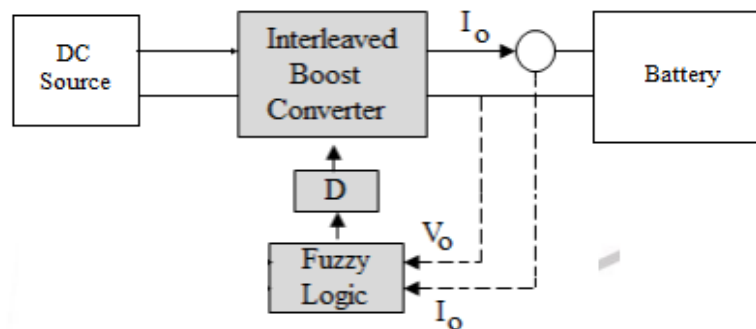


Fig 2. Two-phase Interleaved boost converter

A two-phase interleaved boost converter consists of two identical boost converter modules connected in parallel and operated with a  $180^\circ$  phase difference between their switching signals. Each phase includes an inductor, a controlled power switch, and a diode, while the output capacitor and load are common to both phases. During the ON state of a switch, energy is accumulated in the corresponding inductor from the DC input source. When the switch is turned OFF, the stored energy is transferred to the output through the diode, thereby boosting the output voltage above the input level. Due to interleaved operation, while one phase is storing energy, the other phase simultaneously delivers energy to the load. This complementary action effectively minimizes input current ripple and output voltage ripple compared to a conventional single-phase boost converter. The output capacitor further smooths the voltage and ensures a continuous current supply to the load. Owing to its higher efficiency, reduced stress on components, improved thermal performance, and enhanced power handling capability, the interleaved boost converter is particularly well suited for high-power systems and electric vehicle applications.



**B. Fuzzy Logic Controller**

Fuzzy logic has emerged as a powerful approach for addressing complex and nonlinear problems. In recent years, the role of inference-based techniques in dealing with uncertainty has gained significant attention in engineering applications. Many real-world problems encountered by researchers and engineers cannot be effectively solved using traditional mathematical or numerical methods alone. Fuzzy logic provides an efficient framework for modeling and controlling systems whose dynamics are unknown, uncertain, or difficult to describe analytically. By representing the vagueness inherent in linguistic terms and human reasoning, fuzzy theory enables the incorporation of human-like decision-making and common-sense reasoning into system analysis and control.

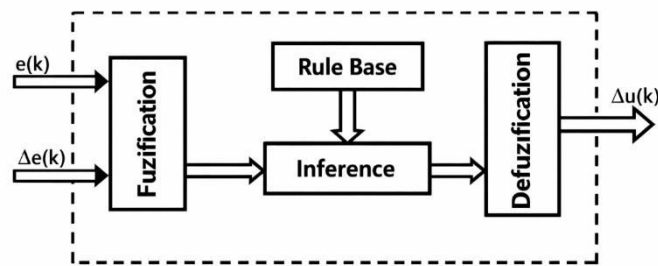


Fig 3. Block diagram of Fuzzy Logic Controller.

In a bidirectional DC–DC converter, a fuzzy logic controller (FLC) is employed to achieve intelligent and reliable control of power flow between two DC sources, such as a battery and a DC link. Unlike conventional PI or PID controllers that depend on accurate mathematical models, the FLC is based on linguistic rules and approximate reasoning, making it well suited to handle nonlinear behavior, parameter variations, and uncertainties commonly present in power electronic converters. The controller processes the error and the change in error as input variables to generate appropriate control signals that regulate the duty cycle. This approach ensures stable voltage or current regulation under diverse operating conditions. The fuzzy logic controller also enables smooth transitions between buck mode during charging and boost mode during discharging, ensuring efficient bidirectional energy transfer. Furthermore, the use of fuzzy logic enhances dynamic response, reduces steady-state error, minimizes overshoot, and improves overall system reliability under varying load and source conditions. As a result, fuzzy logic–based control offers superior robustness, faster response, and greater adaptability compared to traditional control strategies in bidirectional DC–DC converter applications.

The fuzzy control rules table is shown in Table 1 in these ZE stands for Zero, NB for Negative Big, NM for Negative Medium, and NS for Negative Small. PS stands for Positive Small, PM for Positive Medium, and PB for Positive Big.

Table 1 : The rules table for the fuzzy control

de/e	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NM	NM	NS	ZE
NM	NB	NB	NM	NS	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NM	NS	NS	ZE	PS	PS	PM
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PS	PM	PB	PB
PB	ZE	PS	PM	PM	PB	PB	PB



III. DESIGN METHODOLOGY

A. Design of Two-phase Interleaved Boost Converter

The formula for a two-phase interleaved boost converter is:

Duty ratio :  $D = 1 - \frac{V_s}{V_0}$  (1)  
 $D = 1 - \frac{24}{48}$   
 $D = 0.5$

Output current :  $I_0 = \frac{P_0}{V_0} = 2.083A$  (2)  
 Where  $P_0 = 100W$

Input current :  $I_{in} = \frac{I_0}{1-D} = 4.166A$  (3)  
 Here we have load,

$R = \frac{V_0}{I_0} = 23.043\Omega$  (4)

Inductor (L) :  $L = \frac{DV_{in}}{f_s \Delta I_{in}}$  (5)  
 Where  $\Delta I_{in} = 0.4166$

$L = \frac{0.5 \cdot 24}{50000 \cdot 0.4166}$   
 $L = 576.09\mu H$

Capacitor (C) :  $C = \frac{DI_0}{f_s \Delta V_0}$  (6)  
 Where  $\Delta V_0 = 0.03$

$C = \frac{0.5 \cdot 2.083}{50000 \cdot 0.03}$   
 $C = 694.33\mu F$

For Two-phase interleaved boost converter

Inductor :  $L_1 \& L_2 = \frac{DV_{in}}{f_s 2 \Delta I_{in}}$  (7)  
 $L_1 \& L_2 = 288.046\mu H$

Capacitor :  $C = \frac{DI_0}{f_s 2 \Delta V_0}$  (8)  
 $C = 347.166Mf$

B. Design of fuzzy logic controller

Fuzzy membership functions:

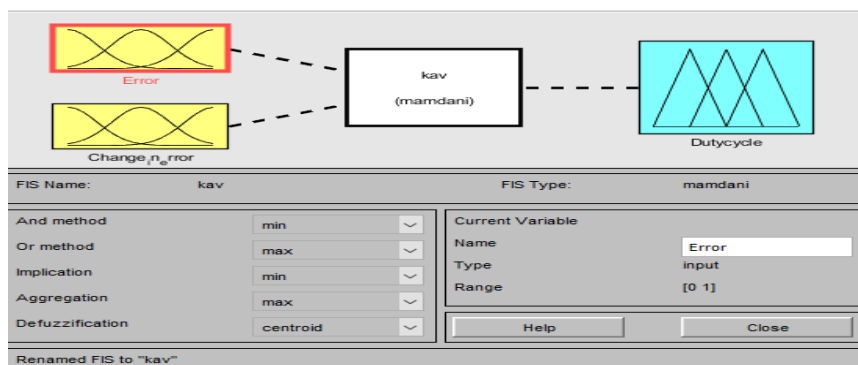


Fig 4. Overall structure of the mamdani-type of fuzzy logic controller



Figure 4 illustrates the block-level structure of the Mamdani-type fuzzy inference system (FIS). The controller takes two input variables, namely the error and the change in error, and produces the duty cycle as the output. Using AND logic with min–max inference and centroid-based defuzzification, the fuzzy controller converts the inferred fuzzy output into a precise duty cycle value. This duty cycle is then used to regulate the converter and maintain the desired output voltage.

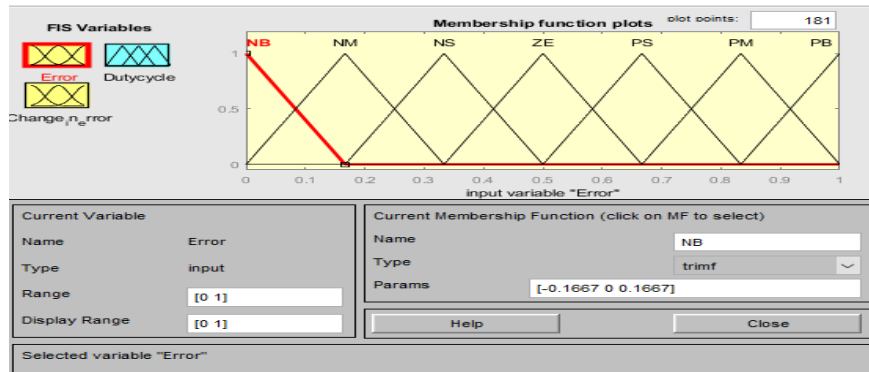


Fig 5. Membership function of input variable-Error

As illustrated in Fig. 5, the first input variable, referred to as Error, represents the deviation of the actual voltage or current from its corresponding reference value.

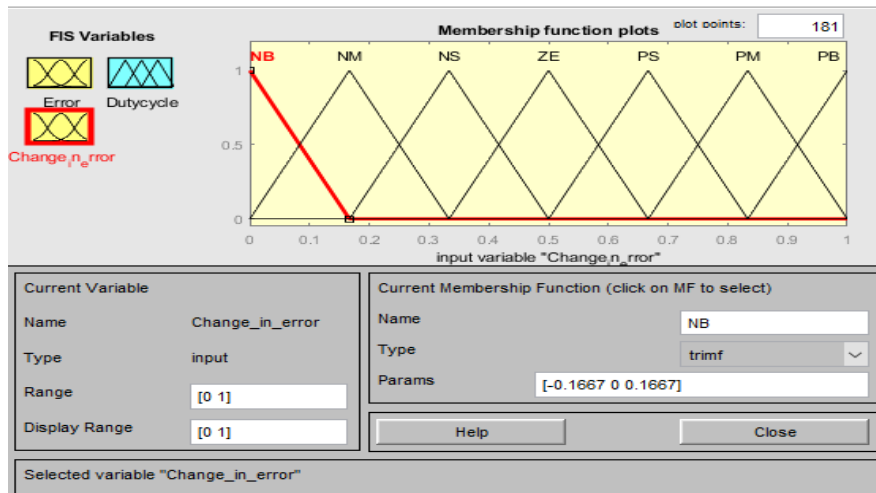


Fig 6. Membership function of input variable-Change in Error

Figure 6 shows the membership function of the input variable change in error for the fuzzy logic controller developed in MATLAB. The controller output, represented by the duty cycle, is defined within a normalized range of 0 to 1.

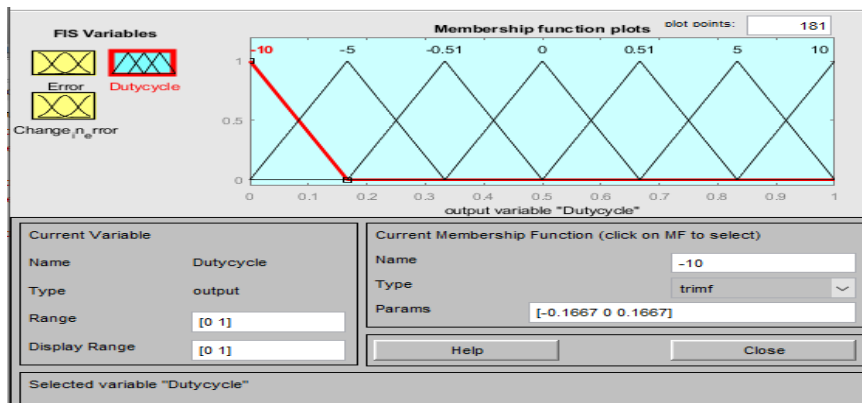


Fig 7. Membership function of output variable-Duty cycle

Figure 7 illustrates the membership function of the output variable, duty cycle, for the fuzzy logic controller developed using MATLAB. The duty cycle is defined within a normalized range of 0 to 1, which corresponds to the practical switching duty ratio required for the operation of the converter.

#### IV. SIMULATION RESULTS AND DISCUSSION

The parameters used in the simulation is provided in table 2:

Parameters	Values
Input Voltage (V)	24V
Output Voltage (V)	48V
Power (P)	100W
Switching frequency ( $f_{sw}$ )	50kHz
Duty ratio	50%
Load (R)	23.043Ω
Inductor (L)	576.09μH
Capacitor (C)	694.33μF
Inductors ( $L_1$ & $L_2$ )	288.046μH
Capacitor ( $C_0$ )	347.166μF

Table 2: Design Specification of the system

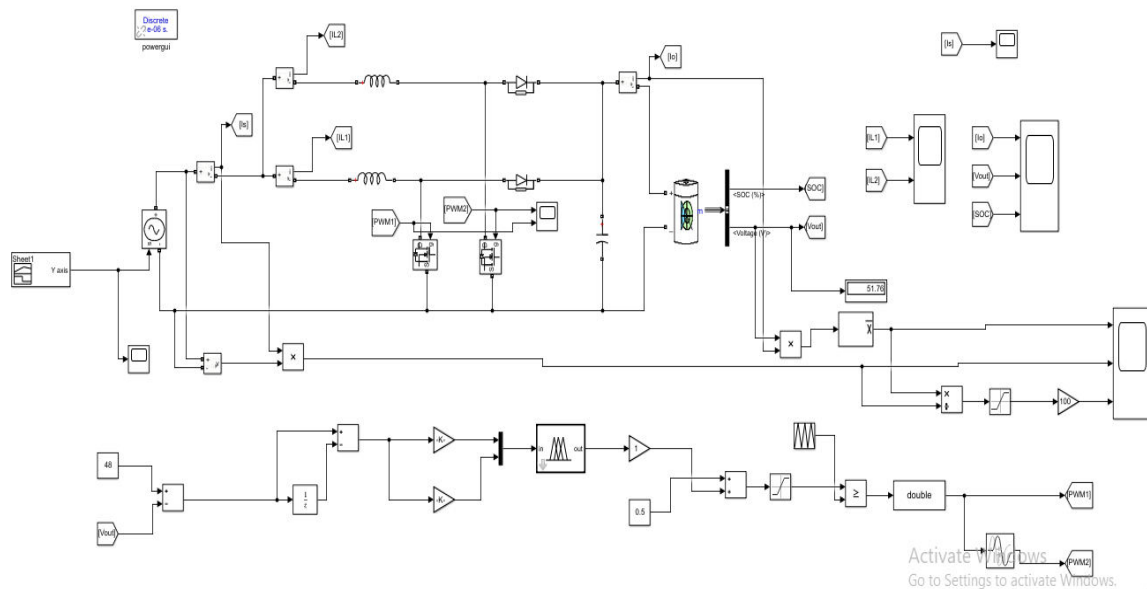


Fig 8. Simulation of two-phase interleaved boost converter with Fuzzy logic Controller

Figure 8 presents the simulation model of an interleaved boost converter controlled using a fuzzy logic controller. The simulation results show that an input voltage of 24 V is boosted to an output voltage of approximately 52 V. In this configuration, the inductors  $L_1$  and  $L_2$  are each rated at 288.046  $\mu\text{H}$ , while the output capacitor has a capacitance of 347.166  $\mu\text{F}$ .

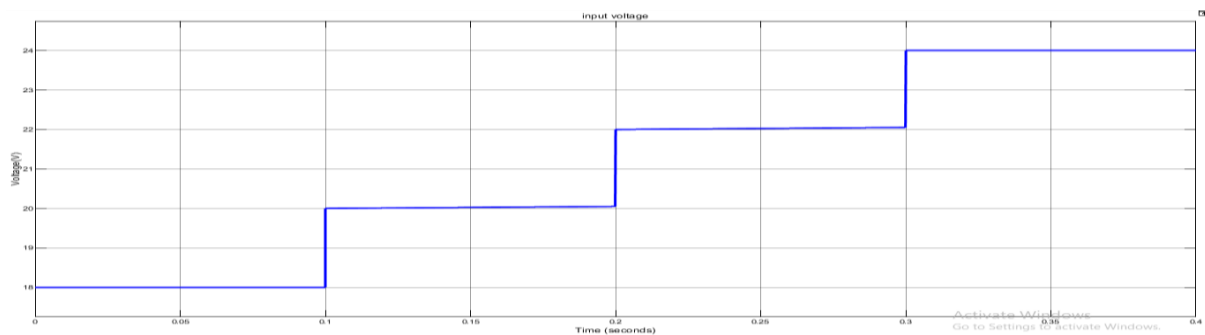


Fig 9. Waveform of Input Voltage of the converter

The input voltage waveform applied to the converter during the simulation is illustrated in fig. 9. To evaluate the voltage regulation capability of the system and the performance of the proposed controller, the input voltage is progressively varied from 18V to 24V.

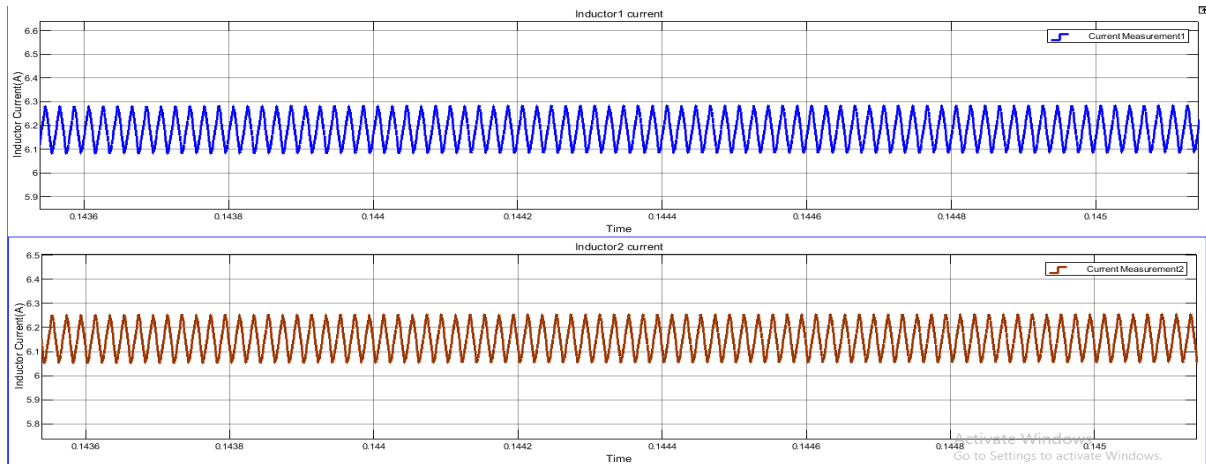


Fig 10. Waveform of Inductor currents 1& 2 of fuzzy logic controller

The inductors share the input current uniformly, as illustrated in Fig. 10. Both inductor currents exhibit a triangular ripple pattern, which is a characteristic behavior of boost converter inductors operating in continuous conduction mode (CCM).

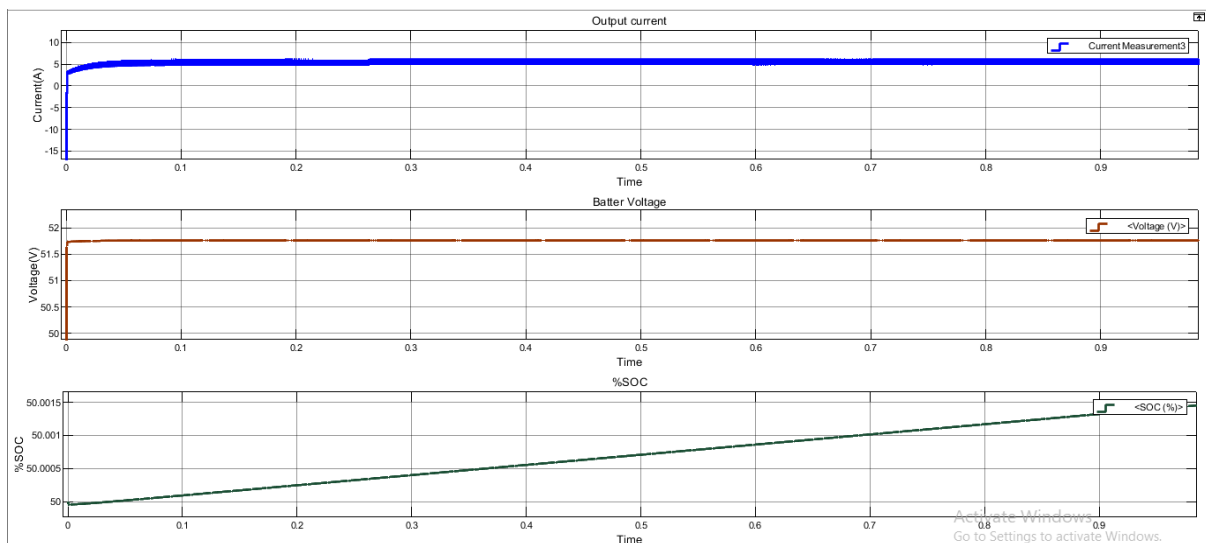


Fig 11. The fuzzy logic controller's output current, battery voltage, and percentage of SOC.

Figure 11 presents the simulated waveforms of the output current, battery voltage, and state of charge (SOC). The results indicate that the output voltage stabilizes at approximately 52 V, while the output current is around 6 A. Additionally, the SOC shows an increasing trend, confirming effective energy transfer and proper charging behavior of the system.

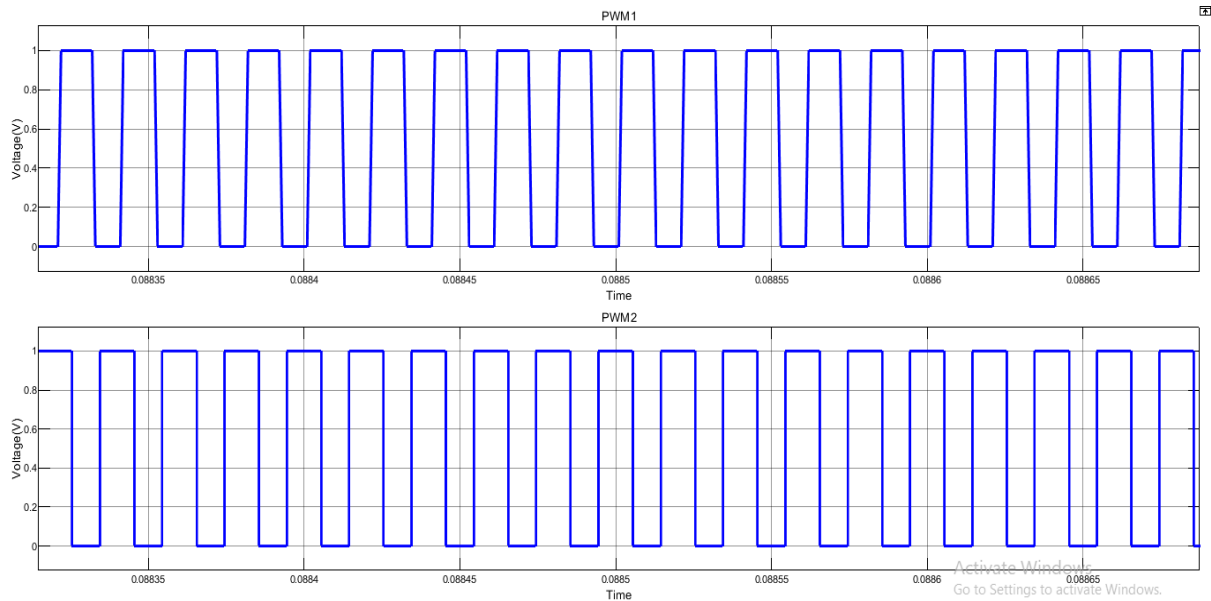


Fig 12. Waveform Gate pulse of PWM1 and PWM2 of fuzzy logic controller

Figure 12 illustrates two pulse width modulation (PWM) signals generated in Simulink, labeled PWM1 (upper signal) and PWM2 (lower signal). These signals are used to control the two switching devices of the two-phase interleaved boost converter operating under a fuzzy logic control scheme.

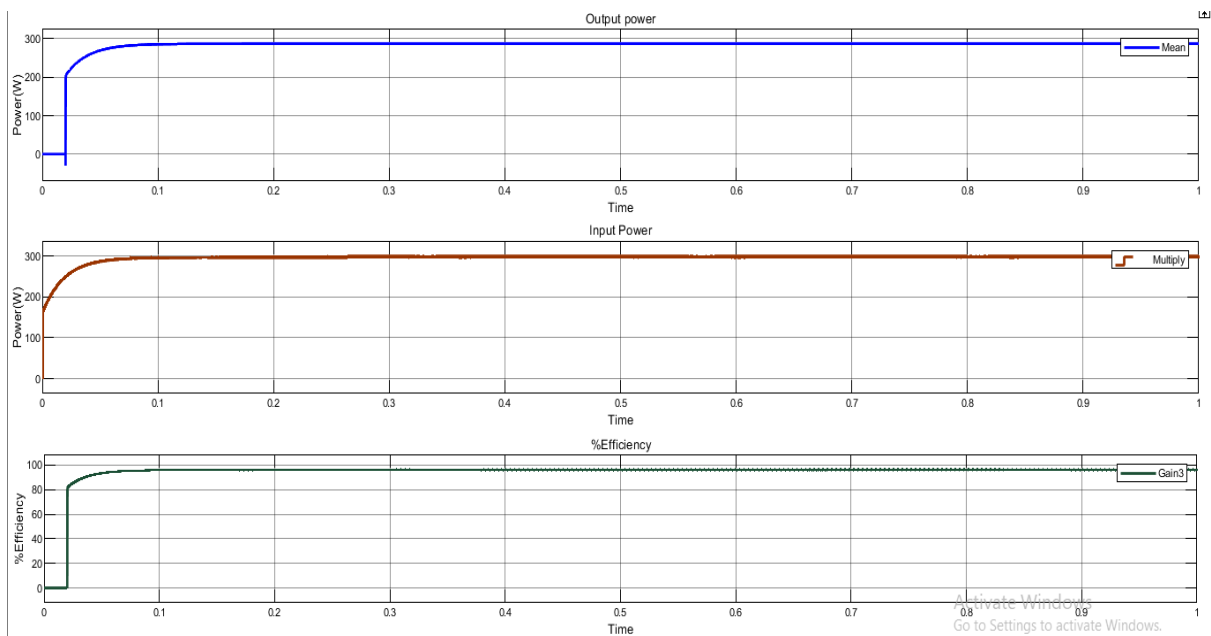


Fig 13. Waveform of output power, input power and %Efficiency of Fuzzy logic controller

Figure 13 shows that the input power is approximately 300 W, while the output power is about 285 W, resulting in an efficiency close to 96%. During startup, the output power increases rapidly and settles to a steady-state value with minimal oscillations, demonstrating the fast transient response and effective dynamic performance of the fuzzy logic controller.

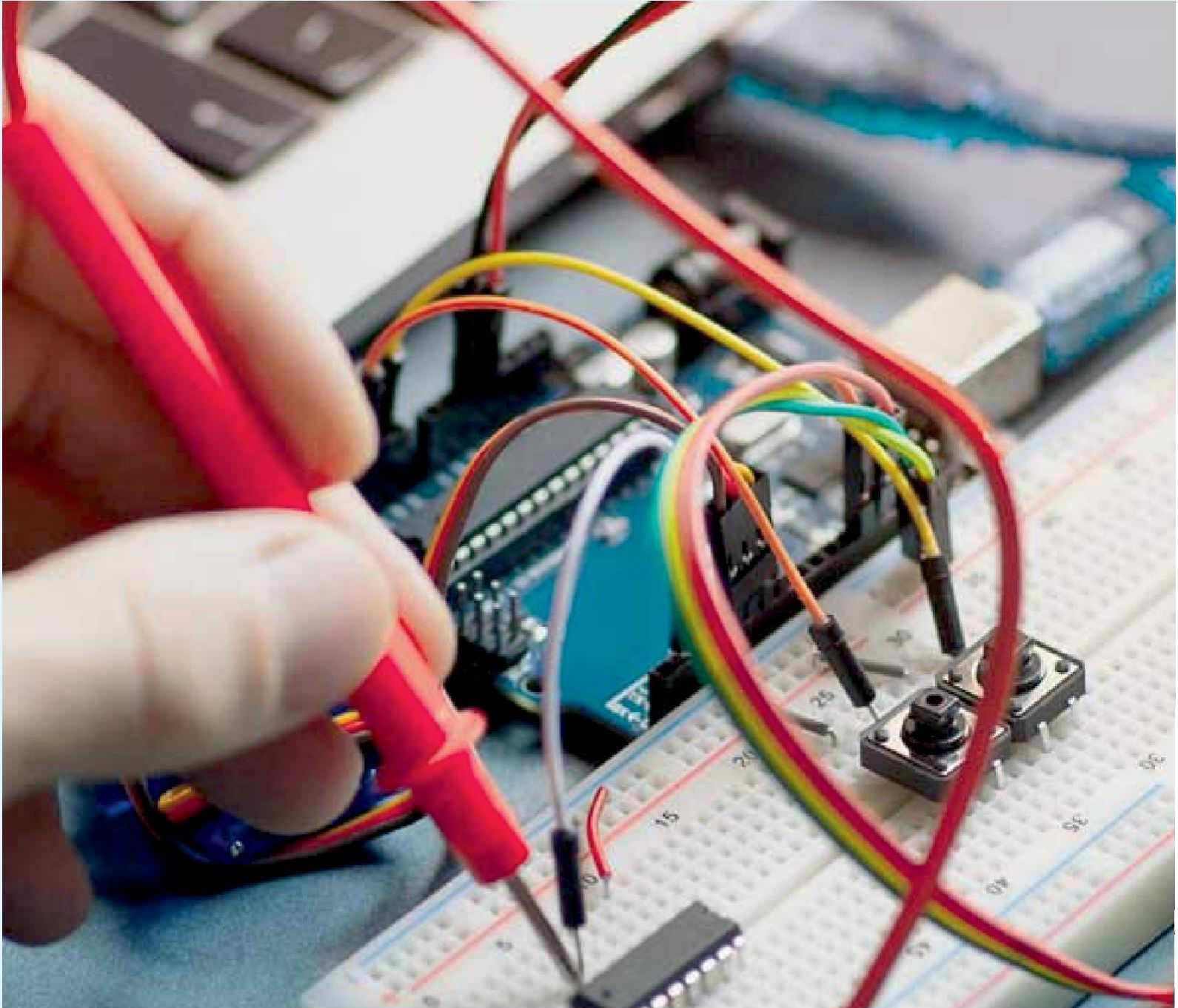


## V. CONCLUSION

Simulation results indicate that the proposed system achieves superior performance compared to conventional boost converters, particularly in terms of efficiency, ripple minimization, and dynamic behavior. Owing to the simplicity, robustness, and effectiveness of the fuzzy logic-based control approach, the converter is well suited for modern electric vehicle charging applications and renewable energy integration. Future work can focus on hardware implementation and real-time experimental validation to further demonstrate the practical applicability of the proposed methodology.

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