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Off board EV Charger with SEPIC Converter

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Abstract: Charging an EV using external infrastructure (off-board charging) involves dedicated stations featuring AC/DC power conversion stages and control mechanisms to manage the charging process safely and efficiently. The fundamental architecture of these converters (unidirectional or bidirectional AC-DC and DC-DC) is a primary determinant of the system's cost, physical footprint, efficiency, and functional capabilities. Fast charging via high-power converters not only benefits users but also provides grid ancillary services. A significant challenge emerges; however, as expanding EV fleets and renewable energy penetration into distribution networks generate harmonics. This harmonic pollution deteriorates power quality, potentially compromising grid operation, safety, and dependability. Therefore, advancing power converter technology, refining charging methodologies, and improving grid interconnection strategies are essential to fully realize the potential of electric vehicles. In this paper a SEPIC converter for charging of electric vehicle in an off boards charging technique. The system is proposed to integrate a PV source and energy storage system. The converter is controlled through a fuzzy logic controller with a view to improve dynamic response of the charging system.
Keywords: EV Charging, SEPIC, duty cycle, bidirectional converter

I. INTRODUCTION

Off-board EV chargers are external devices that provide power to electric vehicles. They come in various types, ranging from slow Level 1 chargers used for home charging to fast Level 2 and DC chargers found in public charging stations [1]. These chargers offer flexibility, scalability, and efficiency, making them essential for extensive acceptance of EVs. Factors to consider while selecting off-board charger are - vehicle compatibility, charging speed, installation requirements and cost [2].
The conversion of grid AC input to battery-compatible DC output in off-board EV chargers is fundamentally achieved through power converters. [3]. This conversion process is crucial for safeguarding and efficient charging. The power converters involved in EV charging are rectifiers and DC - DC converters. These converters are often controlled one to prevent characteristics degradation and malfunction of the system due to the voltage disturbances [4, 5, 6]. A step-up type (boost) converter is deployed in a system to increase the voltage above input value. Many renewable energy systems use boost converter, CUK converter and buck boost converter in MPPT systems [9]. These converters have associated shortfalls like low efficiency in presence of disturbances, no isolation between input and output, high ripple contents, slow transient response etc. A SEPIC converter has been recently introduced in the renewable energy applications for voltage step up operation. It offers advantages like- low ripples in output, non-inverted output, isolation and true shutdown capability [7], [8].
Integrating photovoltaic arrays into EV charging networks provides a sustainable pathway to decrease fossil fuel consumption and mitigate environmental impact from greenhouse gases. Off-board EV charging systems, where the charger is external to the vehicle, leverage solar energy to power EVs, offering scalability and flexibility. Off-board PV-EV charging systems typically comprise PV arrays, DC-DC converters, energy storage systems (ESS), and power management controllers. Standalone systems rely solely on solar energy and ESS, while grid-tied configurations use the grid as a backup [10]. The PV array converts sunlight to DC electricity, which is optimized via MPPT algorithms. Esram and Chapman [11] emphasized the role of advanced MPPT techniques, such as perturb-and-observe, in enhancing PV efficiency under varying irradiance. DC-DC converters then adjust voltage levels to match EV battery requirements, ensuring efficient energy transfer [12].
A conventional boost converter has associated drawbacks of drawing large current from the source which may cause damage to the semiconductor devices. Also its output voltage is (nearly) equal to the input when the switching device is deactivated. In other words, a boost converter is not a fail-safe device. Further, the voltage regulation techniques of boost converter are complex and may need a non-linear controller. Due these drawbacks and limiting factors, a better topology for voltage boosting is demanded.
In this context, a SEPIC has been gaining attention of researchers. A SEPIC converter is a type of buck-boost converter whose output voltage is controlled by duty cycle. It produces non-inverted voltage at the output and has very low output ripple contents.

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Benefits of the SEPIC converter include lower switching losses, less output voltage noise, increased efficiency, and the ability to operate at high frequencies.

This paper discusses SEPIC converter based off board EV charging mechanism. The system is supported with a bidirectional converter and auxiliary storage element. Results from MATLAB simulations showcase the operational efficiency of the converter and system topology.

II. SEPIC CONVERTER: SCHEME AND OPERATION

The SEPIC converter circuit is seen in Figure 1. Its steady-state operation comprises two intervals: when switch 'S' is ON and when it is OFF. Capacitor C_i is initially assumed fully charged.

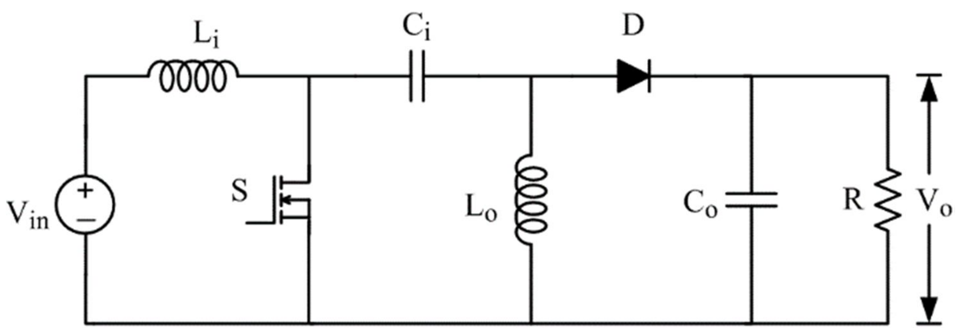

Fig. 1 Circuit Scheme of SEPIC Converter

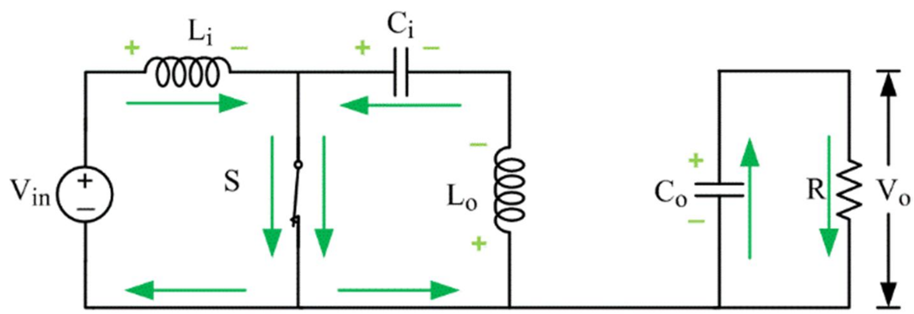

Fig. 2 Operation during switch 'ON'

When the switch is ON (Figure 2), energy from V_{in} flows into inductor L_i. Concurrently, inductor L_o acquires a negative charge, capacitor C_i releases energy via switch S, and capacitor C_o delivers power to load R.

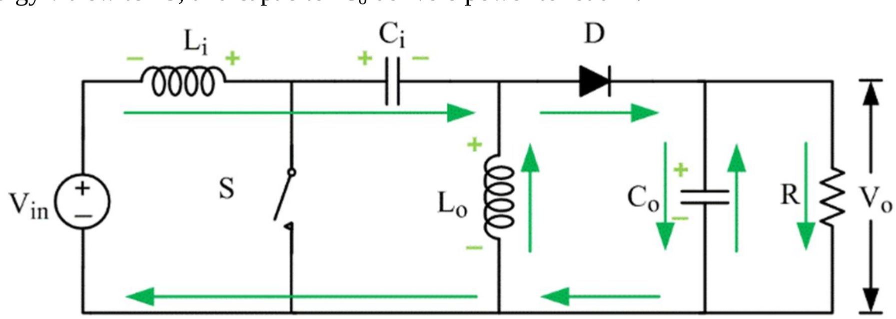

Fig. 3 Operation during switch 'OFF'

During the OFF state (Figure 3), inductor L_i reverses polarity to maintain current direction when switch S opens. This initiates charging of capacitor C_i. Simultaneously, inductor L_o maintains its current, causing its stored energy to invert polarity. This polarity reversal forward-biases diode D, enabling capacitor C_o to charge. Once charged, C_o delivers energy to load R. The SEPIC converter's output voltage is expressed as:

$$V_0 = \frac{d}{1-d} V_{in} \quad \ldots \quad (1)$$

Where, d = duty cycle.

III.SIMULATION AND RESULTS DISCUSSION

Figure 4 illustrates the MATLAB system model. A PV system generates renewable energy, supplying power to a SEPIC converter operating in boost mode (though buck mode is also possible via duty cycle adjustment). System specifications are detailed in Table 2. A fuzzy logic controller (FLC) generates the PWM control pulses and reference current. The FLC uses two inputs: voltage error (reference minus actual) and the change in error, processed through a 7x7 rule matrix. Membership functions for the error, change in error, and FLC output are shown in Figures 5, 6, and 7, respectively.

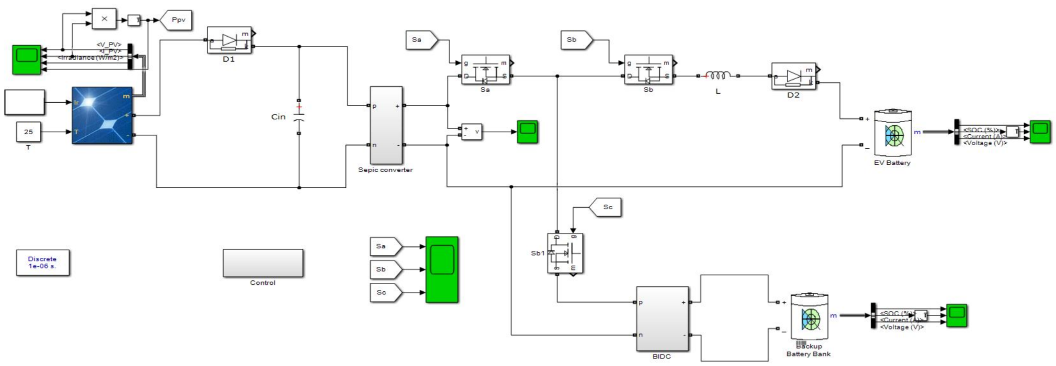

Fig. 4 MATLAB Simulink model of off board EV charging system

TABLE I
Design Specifications

Sr. No.	Components	Specifications
1	PV panel	400W, 30V
2	EV Battery	24V, Ah
3	Auxiliary battery	60V. Ah
4	Bidirectional Converter	Half bridge buck boost
5	Power converter	SEPIC Converter
6	Controller	Fuzzy logic control

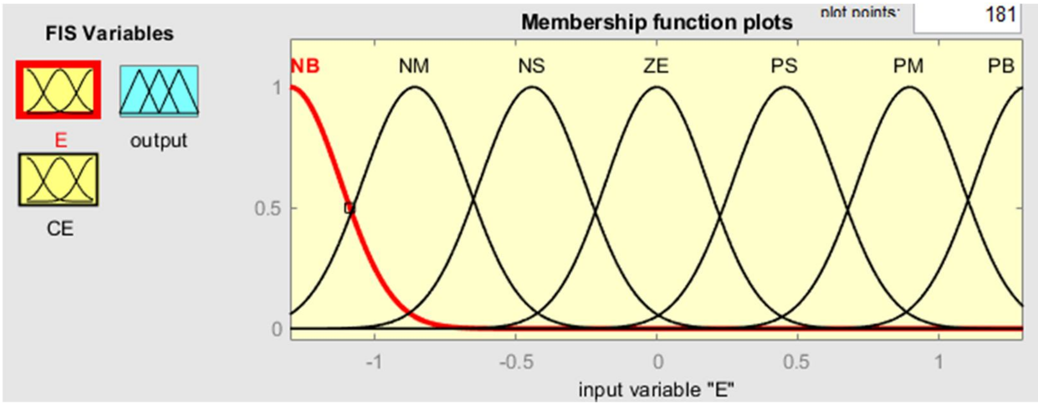

Fig. 5 Membership function of Error signal

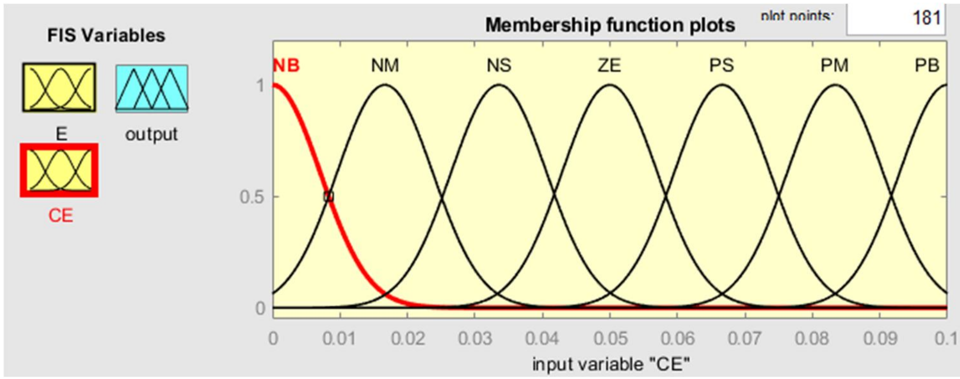

Fig. 6 Membership function of Change in Error signal

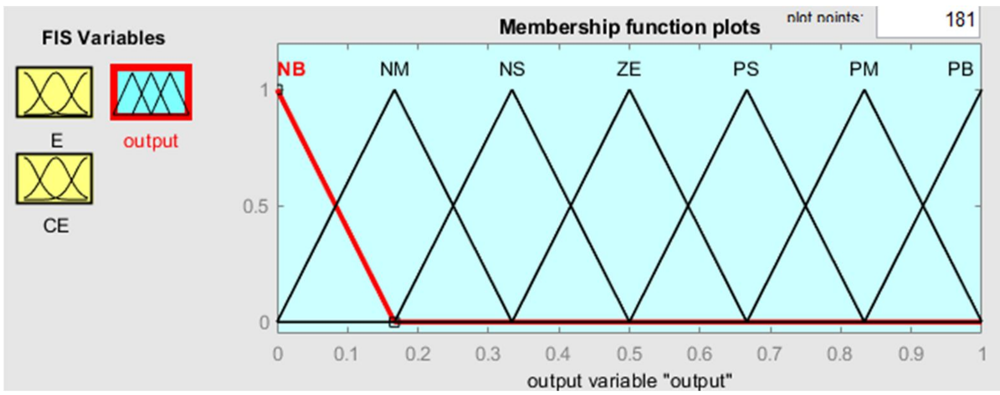

Fig. 7 Membership function of FLC Output

The energy storage element (auxiliary battery) is included in the system with a three stage bidirectional DC-DC converter as seen in figure 8. The operation of this bidirectional converter is based on the power output of PV system. If the power output of PV system is greater than 300W, the simultaneous changing of auxiliary battery is activated along with main EV battery. And when the PV power falls below 200W, the bidirectional converter directs the power flow from auxiliary battery to main EV battery.

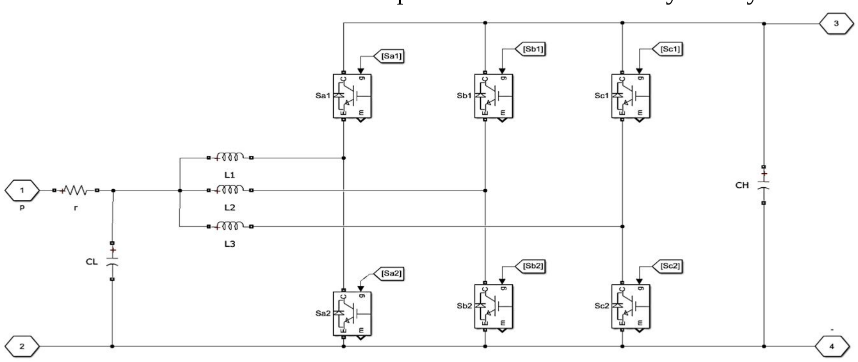

Fig. 8 Three stage bidirectional DC-DC converter

The MATLAB Simulink model is executed for a period of 1 second. In the time interval 0 – 0.4 seconds, the radiations on PV panel are 1000 W/m^2, during 0.4 – 0.6 seconds the irradiance is 200 W/m^2 and after 0.6 second it is at 750 W/m^2. The system analysis is done during these three phases of the solar radiations. As seen in figure 9, the variations in irradiance cause PV power output to fluctuate accordingly. In the simulation model, if the PV irradiance is below 500 W/m^2 or PV power is between 200 – 300W, the charging of auxiliary battery and EV battery from PV panel is disabled. The auxiliary battery charges only when solar irradiance exceeds 800 W/m^2 or PV power surpasses 300W. In contrast, the EV's main battery charges continuously. The SEPIC converter maintains a constant 28V output to supply the DC link, which charges the EV battery. This shared DC link also connects to the auxiliary battery through a bidirectional DC-DC converter.

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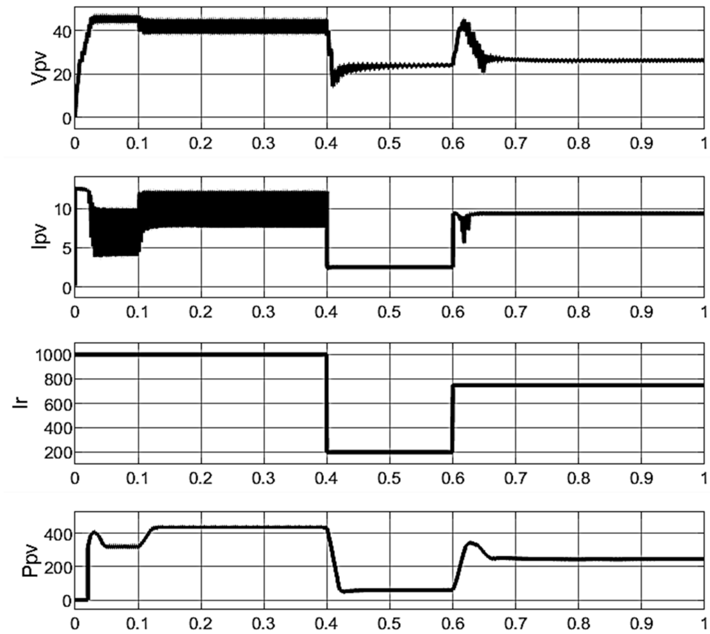

Fig. 9 PV Voltage and current with respect to radiations

The SEPIC converter provides regulated 28 V DC link voltage for the 24V EV battery. Charging the auxiliary battery necessitates boosting this voltage to 60V via a bidirectional DC-DC converter. The DC link output voltage of SEPIC converter is seen in figure 10. The status of MOSFET switches Sa, Sb and Sc are indicated in figure 11. The switch Sa is responsible for connecting the PV system with EV battery and auxiliary battery. The switch Sb is responsible for connecting the DC link between the bidirectional converter and EV main battery while the switch Sc connected and disconnect the bidirectional converter and thereby the auxiliary battery with the DC link.

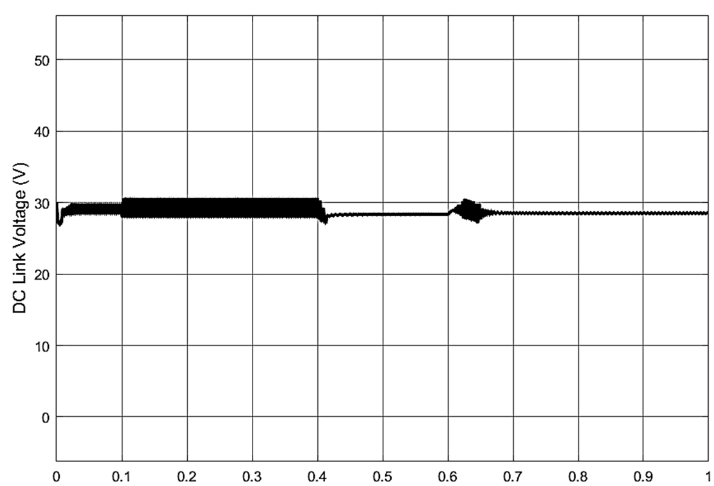

Fig. 10 DC LInk Voltage for battery charger

The graph of state of charge, current and voltage of auxiliary battery are indicated in figure 12. During the time interval 0 – 0.4 seconds the graph of SoC is observed to increase and the current is seen in negative direction. It indicates that during this interval the charging of auxiliary battery takes place. During time interval 0.4 – 0.6 seconds, the graph of SoC is seen to be decreasing with current in positive direction, indicates that the auxiliary battery undergoes discharge in this interval. In the interval 0.6 – 1 seconds no action is seen with auxiliary battery since the radiations are below 800 lux and above 500lux.

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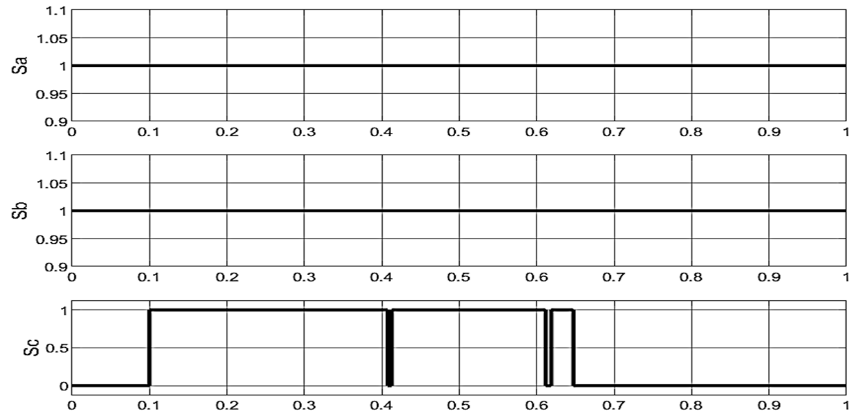

Fig. 11 Status of switches Sa, Sb and Sc

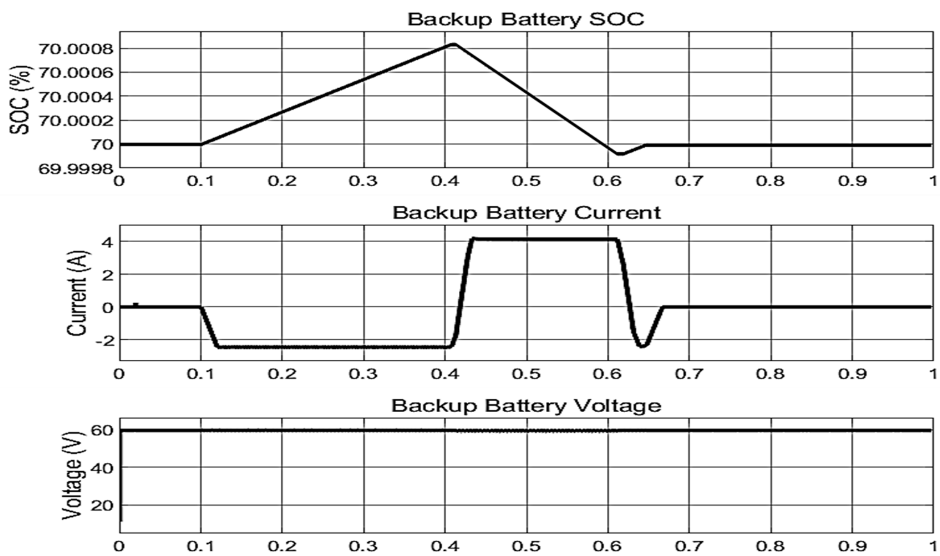

Fig. 12 Voltage, current and SoC of auxiliary battery

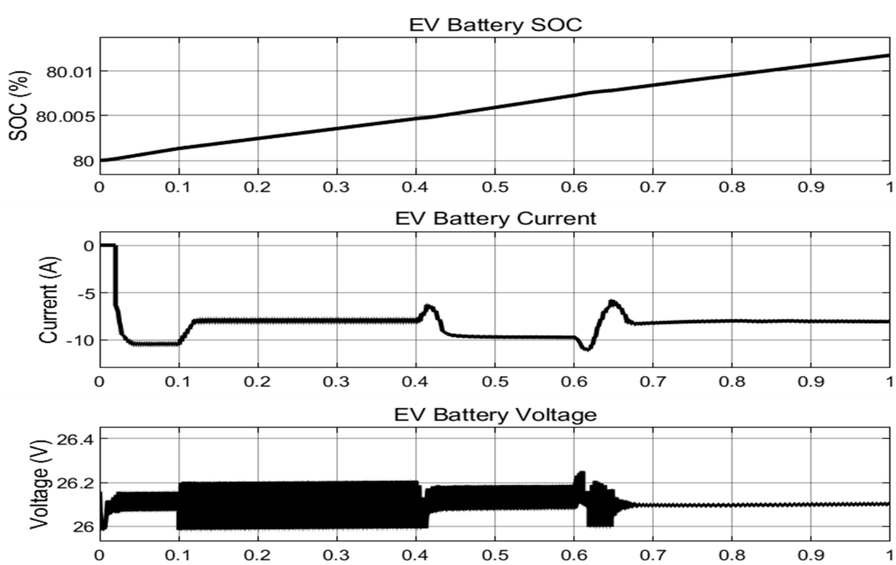

Fig. 13 Voltage, current and SoC of EV battery

The figure 13 describes the charging of EV main battery under various circumstances of PV irradiance. The graph of the SoC is seen to be increasing throughout the simulation interval which indicates continuous charging. However, the value of charging current of the battery is seen to vary as per the power output of the PV panels. Correspondingly, the voltage ripples are seen at the output of the SEPIC converter.

IV. CONCLUSION

An off-board EV charger with a SEPIC converter offers an efficient and flexible solution for charging of EVs. The SEPIC converter provides several advantages in this context, such as the ability to step up or step down the input voltage, making it well-suited for applications where the charger needs to handle variable grid or renewable energy sources. Additionally, SEPIC converters ensure continuous current input, leading to less stress on the components and improved reliability.

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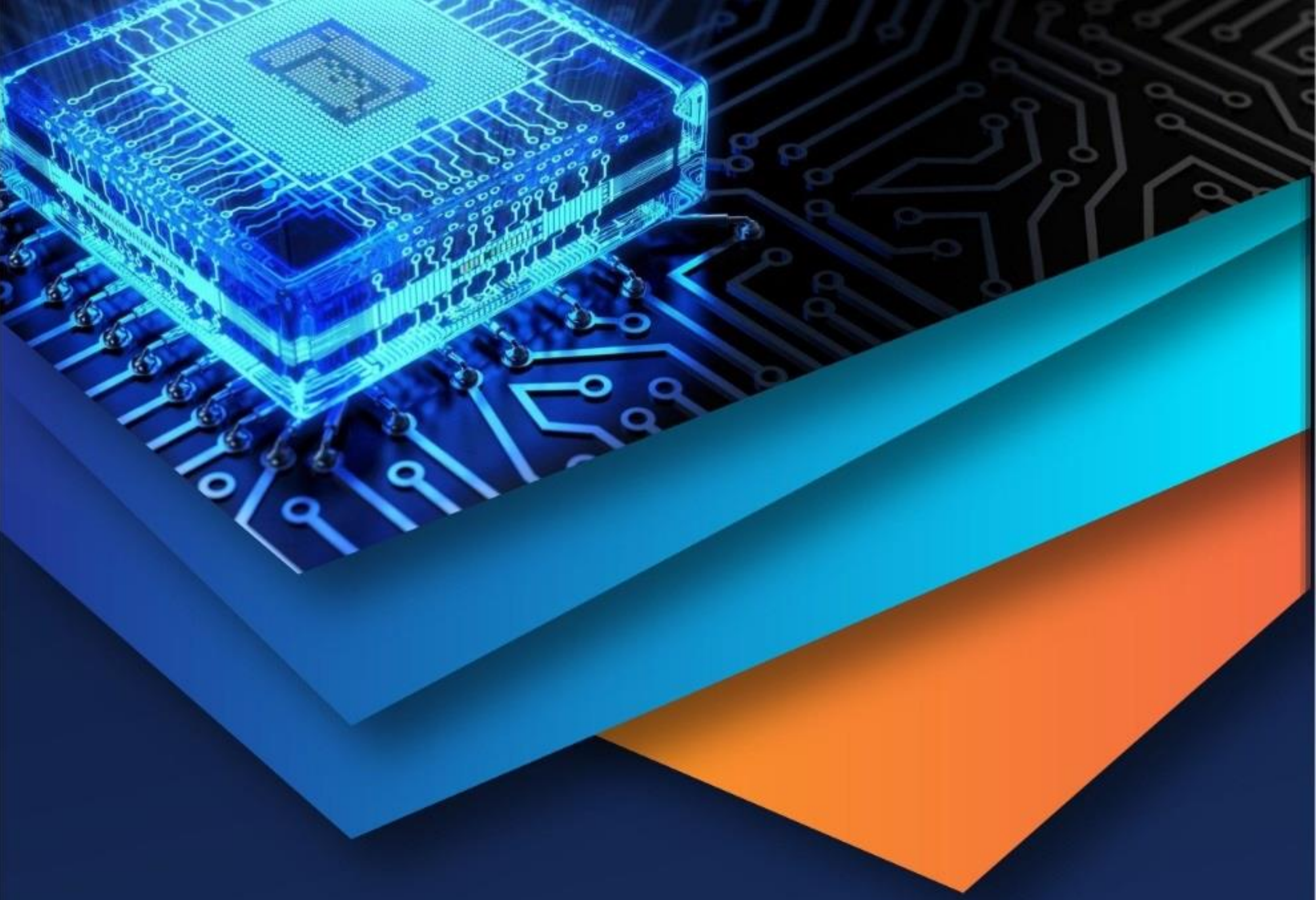

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