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RESEARCH ARTICLE OPEN ACCESS

DESIGN AND ANALYSIS OF NOVEL TOPOLOGY FOR PV-FED EV CHARGING SYSTEM

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ABSTRACT

This paper presents a novel design for a photovoltaic (PV) powered electric vehicle (EV) charging system. The core of the system is a modified single ended primary inductance converter, chosen for its high efficiency, reduced switch voltage stress, and ample operating range for maximum power point tracking (MPPT). This study details the redesigned SEPIC converter architecture, including with and without the MPPT algorithm. Additionally, it presents an optimized parameter selection, design methodology, and simulation technique for analysing the converter's performance in EV charging applications.
Two MPPT approaches, Perturb and Observe (P&O) and Incremental Conductance (IC), are investigated and compared based on their impact on the converter's switching time under standard solar PV panel testing conditions. To comprehensively evaluate the system's performance, a MATLAB/Simulink model is developed, simulating the charging of a 48V, 200Ah battery using a 2kW solar PV input through the modified SEPIC converter and variations in the battery state of charge (SoC), battery voltage, and charging current are monitored. The simulation results demonstrate that under identical simulated conditions (10 seconds), the battery SoC increases from 50% to 50.034% without MPPT and to 50.042% with MPPT, highlighting the effectiveness of the MPPT algorithms in maximizing harvested solar energy.

I. INTRODUCTION

The increasing adoption of electric vehicles necessitates the development of efficient and readily available charging infrastructure. This paper presents a novel approach to EV charging by utilizing a PV-powered system with a modified SEPIC converter. Compared to traditional boost converters, the modified SEPIC offers several advantages, including nearly double the static gain, wider operating range for MPPT controller and reduced switch voltage stress thereby enhancing the converter's reliability and lifespan [1].

The adoption of renewable energy alternatives has increased dramatically due to the rising costs and depletion of non-renewable energy sources. Among these, photovoltaic (PV) energy has drawn quite a bit fascination as a potential remedy for the problems posed by increased energy demand and global warming. Fuel independence, environmental friendliness, durability, and cheap maintenance are just a few advantages of PV energy.

There are many processes involved in integrating PV systems into the grid, one of which is raising the output voltage to meet grid requirements. Boost converters or high-frequency step-up transformers are used in conventional methods. Even though DC-DC converters are frequently used to boost PV system voltage, traditional topologies frequently have poor static gain, which lowers output voltage [2].

As an instance, the maximum input voltage rise that a SEPIC converter with a duty cycle of 0.82 can achieve is a factor of 5. This would need a tenfold increase in input voltage to fulfil grid requirements, making the usage of a step-up transformer redundant.

Modified SEPIC converter architecture is suggested in this study to overcome these drawbacks. With the addition of a diode and a capacitor, the converter may increase the input voltage by up to ten times. Because of this improved capabilities, a step-up transformer is no longer necessary, simplifying the system design and perhaps increasing efficiency.

By investigating modified SEPIC converter architecture that delivers higher output voltage and better efficiency, this research seeks to further PV system integration [2].

II. MODELLING AND DESIGNING

II.1 SOLAR PV SPECIFICATIONS

The design and development of a MATLAB/Simulink model for a solar photovoltaic (PV) system intended to recharge an electric vehicle's (EV) battery is described in the present article. The system is configured to deliver 48V and 200Ah to the battery using Modified SEPIC converter. A constant irradiation of 1000W/m2 and a temperature of 25°C are assumed in the simulation. The PV system incorporates Maximum Power Point Tracking (MPPT) functionality to maximize power output. There are eight parallel modules in the simulated system, and each module has sixty solar cells. The specific design parameters of the PV modules are detailed in Table 1 [3].

Table 1: Solar PV Module Specifications at STC.

Parameter	Specification
Voltage at MPP (V_{MPP})	30.9 V
Current at MPP (I_{MPP})	8.1 A
Power at MPP (P_{MPP})	250.29 W
Open Circuit Voltage (V_{OC})	36.6 V
Short Circuit Current (I_{SC})	8.75 A

Source: Authors, (2024).

II.2 DESIGN OF MODIFIED SEPIC CONVERTER

The power circuitry of the traditional SEPIC converter is presented in Figure 1. A key feature of the SEPIC converter is its ability to both boost (step-up) and buck (step-down) the input voltage, making it suitable for applications with a wide range of input voltages. However the switch voltage is equal the sum of the input and output voltage [4],[5].

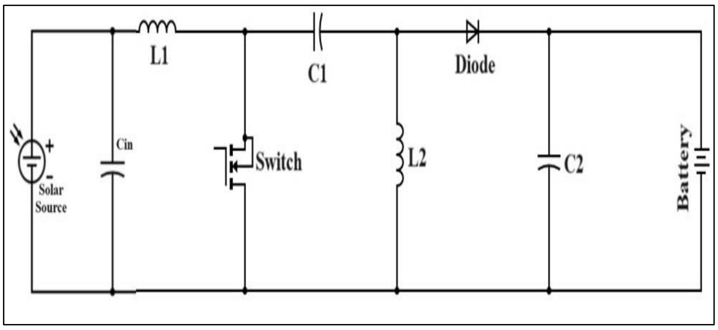

Figure 1. Schematic of Traditional SEPIC Converter.
Source: Authors, (2024).

This topology is modified by incorporating additional components and rearranging the existing components. The schematic of modified SEPIC topology is represented in Figure 2 below [6-10].

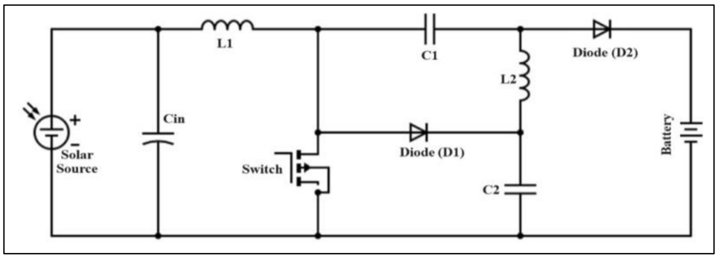

Figure 2: Schematic of Modified SEPIC Converter.
Source: Authors, (2024).

In continuous conduction mode, the duty cycle of the modified SEPIC converter can be determined by

$$Duty\ Cycle\ (D) = \frac{V_{Out} - V_{In}}{V_{Out} + V_{In}} \tag{1}$$

The input current is given by:

$$Input\ Current\ (I_{in}) = \frac{Input\ Power}{V_{In}} \tag{2}$$

The first step in designing a PWM switching regulator is figuring out how much inductor ripple current (ΔI_l) to permit. The inductor ripple current of this topology can be calculated using expression below

$$Inductor\ Ripple\ Current\ (\Delta I_l) = 0.1 * I_{in} \tag{3}$$

The value of inductances can be calculated using the formula

$$L_1 = L_2 = \frac{V_{In} \times D}{\Delta I_l \times F_s} \tag{4}$$

Considering the maximum allowable output ripple to be 2%. The values of capacitances can be determined using the formula

$$C_1 = C_2 = \frac{I_O}{\Delta V_C \times F_s} \tag{5}$$

The change in voltage across the capacitors is determined by

$$\Delta V_C = 0.02\ X\ \frac{V_{out}}{(1-D)} \tag{6}$$

For switching frequency of 20 kHz and analogous input power and load, the various parameters of SEPIC and Modified SEPIC converters are calculated and the values are tabulated below as Table 2 [11].

Table 2: Parameters of SEPIC & Modified SEPIC Topologies.

S.No	Parameter	SEPIC	Modified SEPIC
1	Max. Duty Cycle	64 %	25.6 %
2	Min. Duty Cycle	60.83 %	21.7 %
3	Inductor (L_1)	362 mH	7 mH
4	Inductor (L_2)	362 mH	7 mH
5	Capacitor (C_1)	2.6 mf	1.7 mf
6	Capacitor (C_2)	3.9 µf	1.7 mf

Source: [11].

III. SIMULATIONS AND RESULTS

This study investigates the charging performance of a 48V, 200Ah electric vehicle (EV) battery using a 2kW solar photovoltaic (PV) source with a modified SEPIC converter. The simulation is conducted within the MATLAB/Simulink environment. Key parameters such as voltage, current, and power from the PV panel are monitored alongside the battery's state of charge (SoC), charging current, and voltage. Test conditions are maintained consistent across all scenarios. Figures 3 to 11 present the MATLAB/Simulink models, PV characteristics (voltage, current, and power), battery SoC, charging current, and voltage for the modified SEPIC converter under three configurations: without Maximum Power Point Tracking (MPPT), with Perturb and Observe (P&O) MPPT, and with Incremental Conductance MPPT.

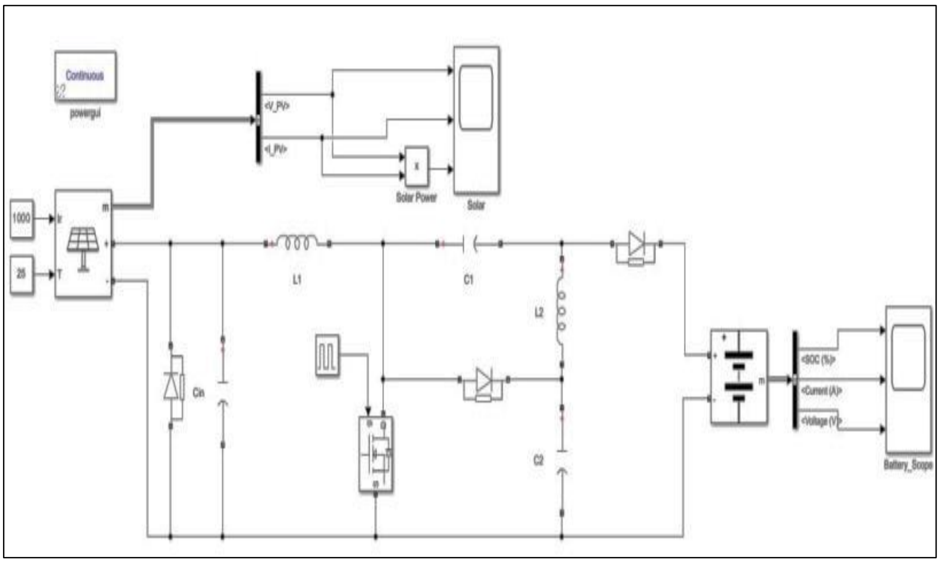

Figure 3: MATLAB/Simulink Model of modified SEPIC converter without MPPT.
Source: Authors, (2024).

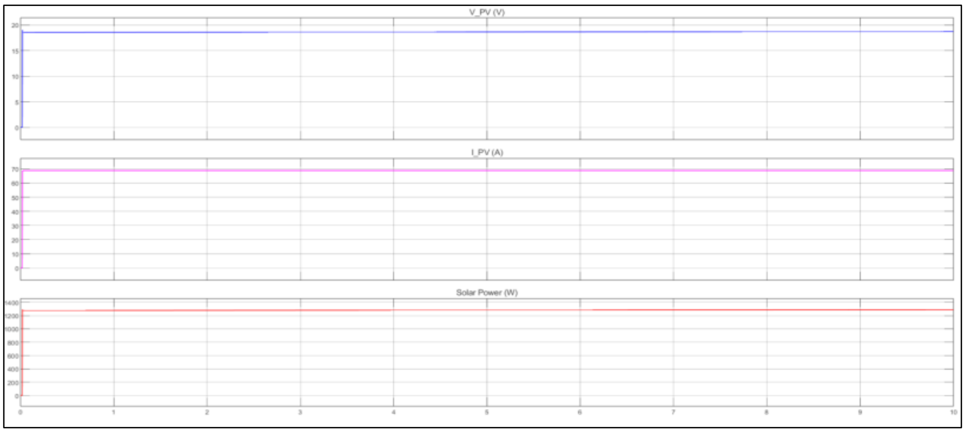

Figure 4 : PV characteristics results for modified SEPIC converter with out MPPT.
Source: Authors, (2024).

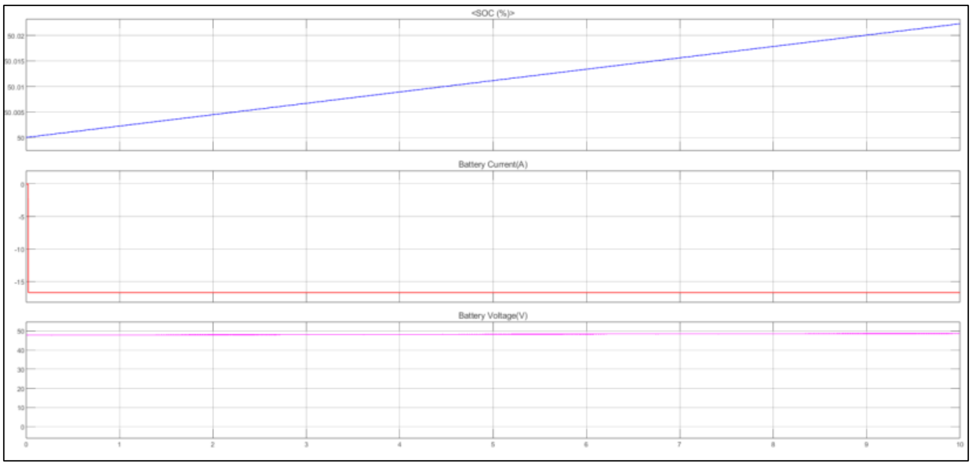

Figure 5: Battery charging results for Modified SEPIC converter with out MPPT.
Source: Authors, (2024).

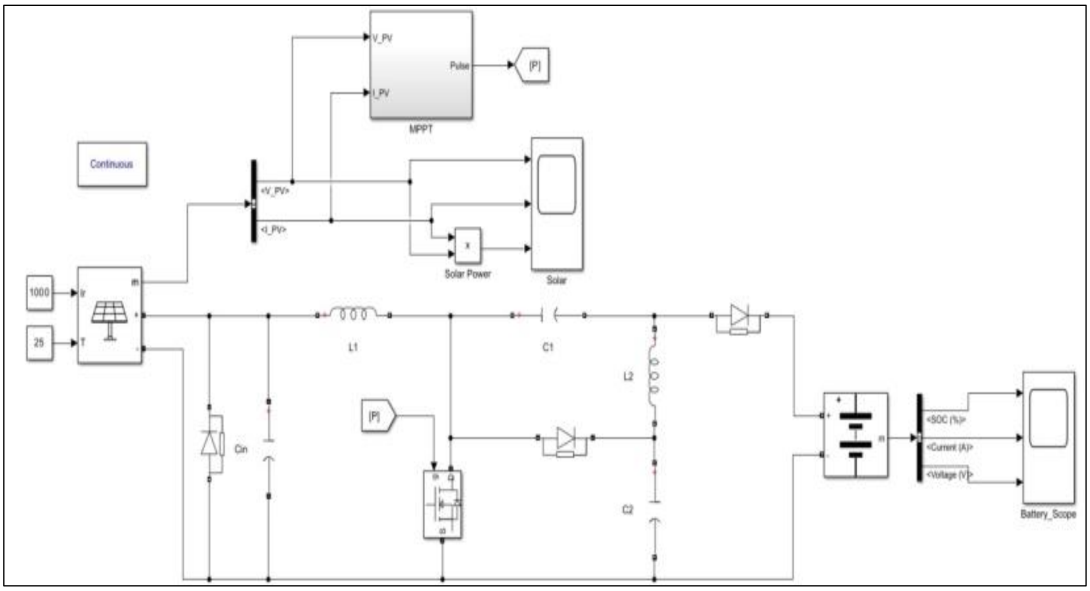

Figure 6 : MATLAB/Simulink Model of modified SEPIC converter with P&O MPPT.
Source: Authors, (2024).

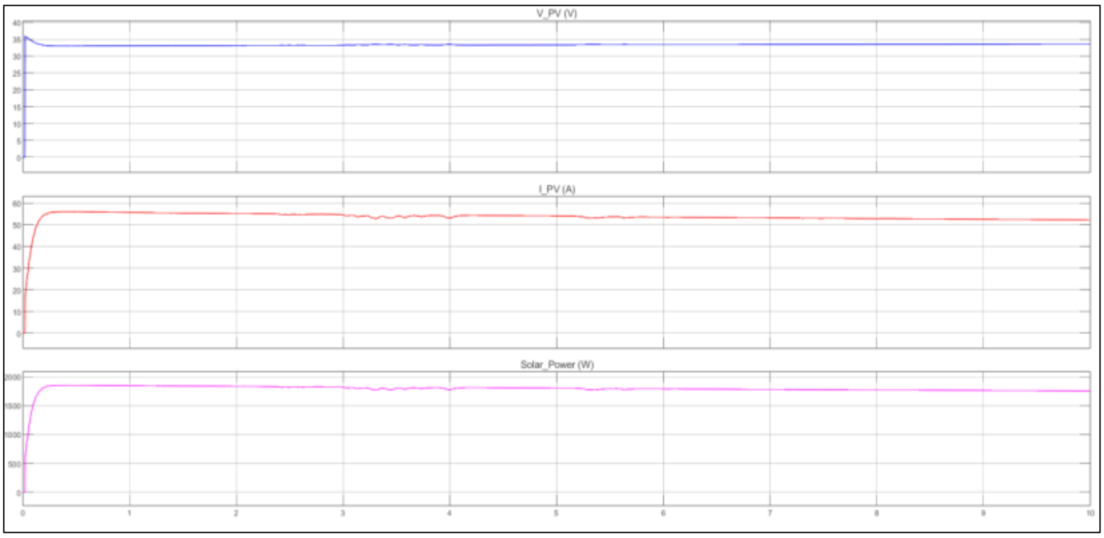

Figure 7: PV characteristics results for modified SEPIC converter with P&O MPPT.
Source: Authors, (2024).

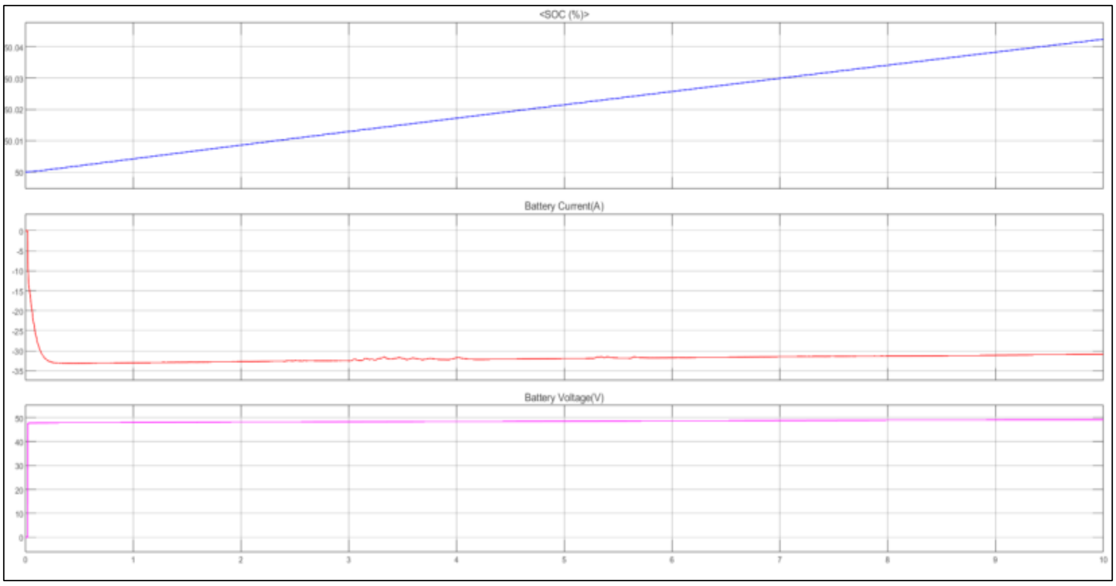

Figure 8: Battery charging results for Modified SEPIC converter with P&O MPPT.
Source: Authors, (2024).

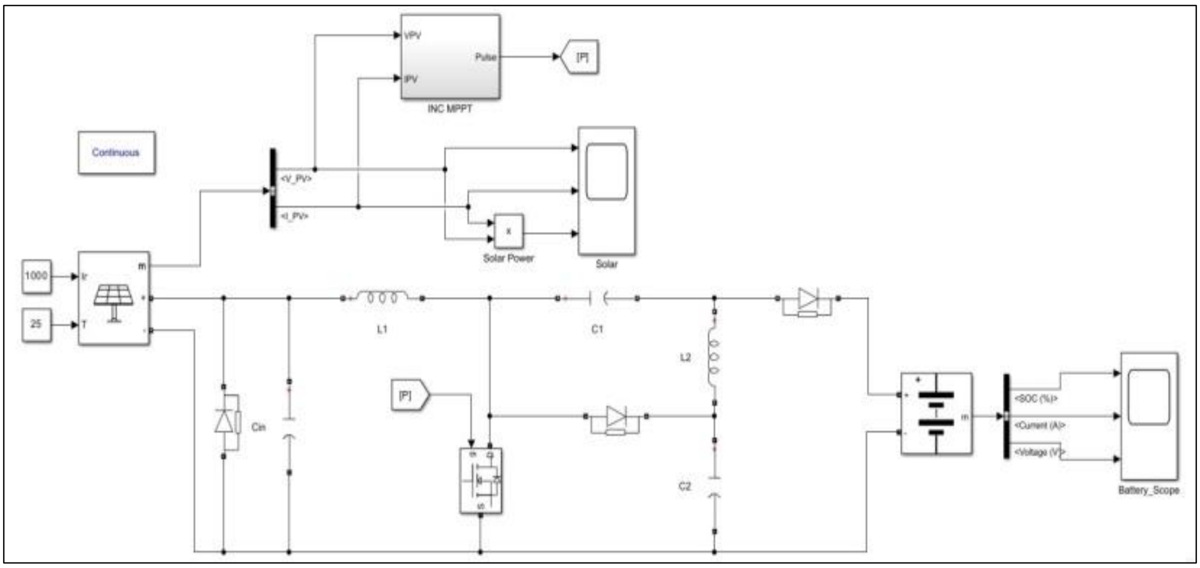

Fig. 9 : MATLAB/Simulink Model of modified SEPIC converter with INC MPPT.
Source: Authors, (2024).

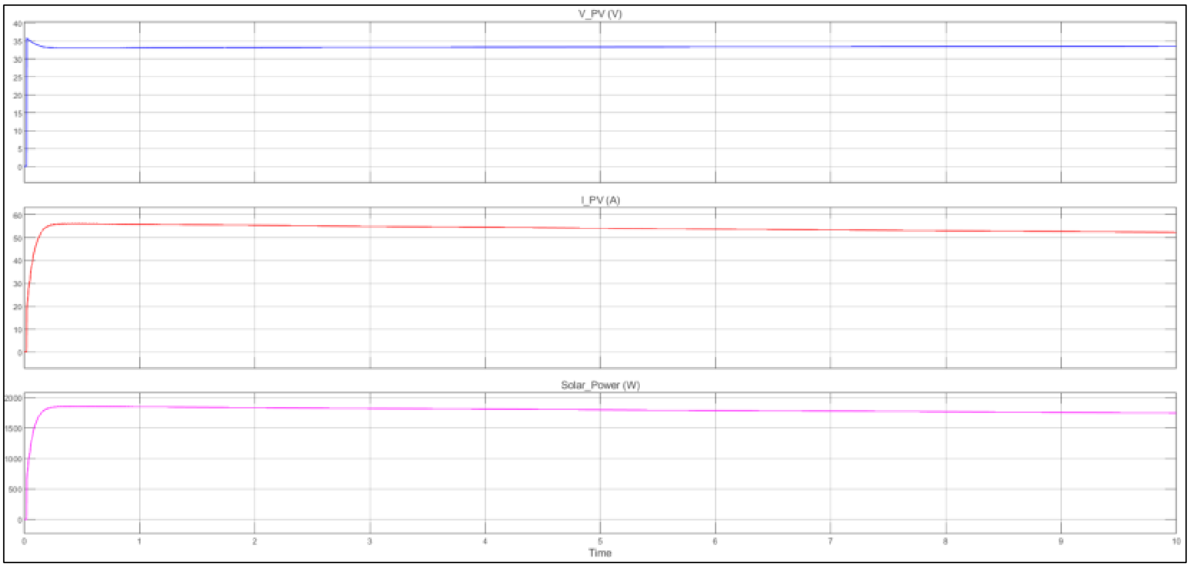

Figure 10: PV characteristics results for modified SEPIC converter with INC MPPT.
Source: Authors, (2024).

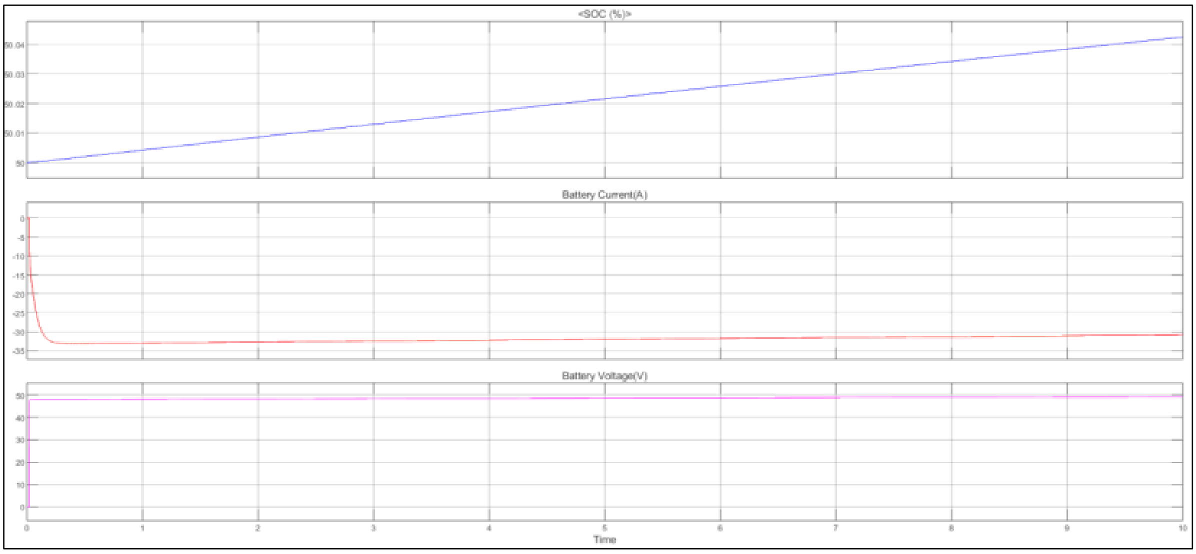

Fig. 11: Battery charging results for Modified SEPIC converter with INC MPPT.
Source: Authors, (2024).

Under identical test conditions, the performances of EV charging system powered by solar PV employing SEPIC and Modified SEPIC converters with and without MPPT methodologies are represented in the table 3. It's important to note that negative battery current values indicate the battery is in charging mode [11].

Table 3: Simulation results with SoC of 50% and simulation time of 10sec.

para meter	**SEPIC Converter**			**Modified SEPIC Converter**		
	With out MPPT	With P&O MPPT	With INC MPPT	With out MPPT	With P&O MPPT	With INC MPPT
SoC (%)	50.02	50.03	50.035	50.034	50.042	50.042
V_b (V)	48.52	48.93	49.01	48.9	49.2	49.3
I_b (A)	-14.84	-23.2	-25.1	-24.17	-30.92	-30.94
V_{pv} (V)	35.59	34.47	34.05	34.76	33.52	33.5
I_{pv} (A)	23.16	41.37	46.6	37.57	52.2	52.25
P_{pv} (W)	824.2	1426	1587	1306	1751	1752

Source: Authors, (2024).

IV. CONCLUSIONS

This paper presented a novel PV-fed EV charging system utilizing a modified SEPIC converter. The proposed system offers several advantages, including high efficiency, reduced switch voltage stress, and the ability to integrate MPPT algorithms for maximizing power extraction from the PV panels. The simulation results demonstrated the effectiveness of the implemented MPPT techniques in enhancing the system's performance compared to the scenario without MPPT. This study paves the way for further research and development of efficient and sustainable EV charging solutions utilizing renewable energy sources. The simulation results demonstrate that the modified SEPIC converter delivers significantly higher current compared to the traditional SEPIC converter, leading to a faster increase in the battery's state of charge. For instance, charging a battery without Maximum Power Point Tracking (MPPT) takes approximately 6.94 hours with a SEPIC converter, while the modified SEPIC converter achieves the same in only 4.09 hours. The advantage persists even with MPPT techniques. Regardless of the MPPT method employed (Perturb and Observe or Incremental Conductance), the modified SEPIC converter consistently achieves faster charging times (3.3 hours) compared to the SEPIC converter (4.63 hours and 3.97 hours, respectively). These findings clearly indicate that the modified SEPIC converter offers a more effective solution for charging electric vehicle batteries using solar power.

V. AUTHOR'S CONTRIBUTION

Conceptualization: Bondu Pavan Kumar Reddy and Vyza Usha Reddy.
Methodology: Bondu Pavan Kumar Reddy and Vyza Usha Reddy.
Investigation: Bondu Pavan Kumar Reddy and Vyza Usha Reddy.
Discussion of results: Bondu Pavan Kumar Reddy and Vyza Usha Reddy.
Writing – Original Draft: Bondu Pavan Kumar Reddy.
Writing – Review and Editing: Bondu Pavan Kumar Reddy.
Resources: Vyza Usha Reddy.
Supervision: Vyza Usha Reddy.
Approval of the final text: Bondu Pavan Kumar Reddy and Vyza Usha Reddy.

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