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Standalone PV Fed Electric Vehicle Battery Charging System

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Abstract: Renewable energy-based electric vehicle (EV), in order to guarantee a consistent and dependable power source, this study presents, a method for charge batteries which incorporates a solar energy system with a backup energy storage system (ESS). The PV system serves as the primary energy source, while excess energy generated during peak sunlight hours is stored in the ESS. During insufficient solar power conditions, such as bad weather or night time, the stored energy is utilized to maintain uninterrupted EV charging. The Proportional-Integral (PI) controller has been employed for regulating both the charging & discharging processes, ensuring stable voltage and current levels while preventing overcharging or deep Discharge from the storage system setup. The method enhances the use of energy, reduces dependence on the grid, and helps establish an environmentally friendly charging network for electric vehicles. Simulation and experimental results validate its effectiveness in maintaining a stable power supply under varying environmental conditions. MATLAB/Simulink software will be used to model a stand-alone, photovoltaic-powered electric vehicle battery charging system.

Keywords: MPPT, Perturb and Observe algorithm, Electric Vehicle battery, Photovoltaic system, Energy Storage System, Converters, PI-Controller.

1. Introduction

Making the move to electric automobiles from traditional automobiles with combustion engines is a significant change with possible solution to the impact that greenhouse gasses and carbon emissions have on our world. Nations and companies worldwide are currently shifting to electric automobiles [1].

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Businesses are setting deadlines for completely switching from conventional to electric vehicles, and governments are providing substantial financial support. Since electrical automobiles do not produce any pollution while functioning silently, automobiles powered by electricity remain eco-friendly [2]. Switching from traditional to electric cars (EVs) will increase the need for electrical energy. Using renewable energy sources is essential for solving that issue, such as solar and wind power, which can be deployed practically anywhere. Using renewable energy sources reduces our Utilization of petroleum and natural gas while simultaneously lowering production of gases that cause global warming. Solar panels and wind turbines, for example, can be erected in homes, offices, or public parking lots where cars are parked for long periods of time [3]. Compared with alternative renewable energy sources, photovoltaic energy systems are simpler as well as more efficient. Solar electricity becomes an appealing choice towards replenishing the batteries of electric vehicles battery. The Proposed system introduces a simplified framework to analysing

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and designing a Standalone Photovoltaic Fed Electric Vehicle Battery Charging System. This framework includes the use of lead-acid batteries enabling storage of energy (as backup), PV panels, along with a battery powered by lithium ion for electric vehicles. However, the bidirectional converter (buck boost) charges and discharges the lead-acid battery, and unidirectional converter (DC-DC Buck converter) charges the electric car [1].

To control the nonlinear properties of a solar PV array, a solar photovoltaic (PV) system requires an effective Maximum Power Point Tracking (MPPT) controller. In order to maximize output power extraction, the MPPT approach makes sure the PV module runs at its ideal voltage, or maximum power point. A buck converter controls the Electric Vehicles (EV) battery charging process, whereas the boost converter controls the power produced by the solar PV system. A proportional-integral (PI) controller controls the power supply output current during the charging and discharging stages, while a bidirectional converter makes it easier to charge and discharge these backup batteries.

Consuming EV is rapidly expanding as concerns about climate changes along with possible exhaustion of natural assets over the years to come mount. However, an increase in EV usage adds additional load for electrical setup. Sustainable sources of energy, notably solar photovoltaic energy, present a possible option. PV energy is particularly advantageous because it is readily available during working hours, making it the ideal energy source for charging electric vehicles. As the As this charging mechanism depend significantly on grid power, that often comes via non-eco-friendly resources like as petroleum and coal, the notion that electric cars are environmentally benign may be brought into dispute [4].

A photovoltaic (PV) array acts as the primary power supply for a standalone charging system. Consisting of solar cells, the PV array can be arranged in a series-parallel configuration to achieve the required voltage and current levels, supplying electricity to the loads [5]. Photovoltaic panels have many advantages, including the ability to generate sustainable energy without releasing harmful greenhouse gases, ease of installation in preferred places, and minimal maintenance costs—although regular cleaning is required to maintain optimal efficiency. Furthermore, solar energy is developing quickly, because of ongoing technological advancements that make solar energy more affordable and lucrative. Because of these benefits, solar PV systems are a great option for renewable energy [6].

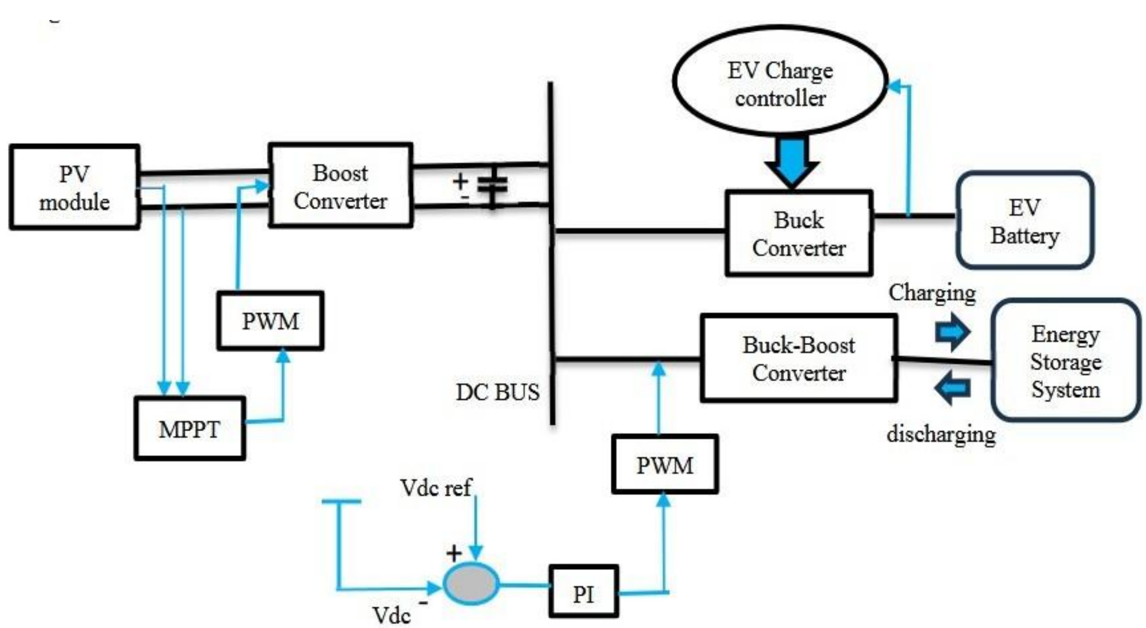


Fig. 1: Configuration of standalone photovoltaic fed electric automobiles battery backup setup.

The framework for a standalone photovoltaic (PV)-fed EV battery setup serves as a key component within Fig.1, operates as an off-grid (as solar PV energy source as a main source of the microgrid for charging). Photovoltaic panels transform sunlight into electrical energy, delivering power to the electric vehicle battery. Yet, because of fluctuations in weather and solar irradiation, the energy produced is irregular. Energy storage systems (ESS) are integrated to mitigate this intermittent behavior. The step-up (boosting *Vdc*) converter, which coupled towards output, allows maximum amount power from a point (MPPT) and modifies the potential level to meet the Vdc bus voltage. The *Vdc* bus is connected towards the two dc/dc converters charging converters: the bidirectional dc/dc converter to control the charging/discharging cycle of the lead-acid storage battery and a unidirectional step down(buck) converter for charging the lithium-ion electric automobile battery. The converters 'analysis and modelling are covered in advance.

2. Methodology

2.1 PV Array

A PV module may be modelled using a familiar methodology same as that of the PV cell, which utilises the similar model of Photovoltaic cell. The schematic comprises an electrical source of current (I_{sc}), a semiconductor diode (*D*), along with the series resistance (R_s). The model excludes parallel resistance (R_p) because of its negligible Effect over a One Module. Additionally, which incorporates the effects of temperature on diode's reverse saturation current (I_o) also along with short-circuit source of current (I_{sc}) to create a more accurate model. With this semiconductor diode idealist factor (*n*) selected, it uses a single diode, for supplying the optimal I-V curve fit. Fig. 2, represents the photovoltaic array (solar cell) equivalent electrical model [5]. The PV array's inputs are temperature and irradiance.

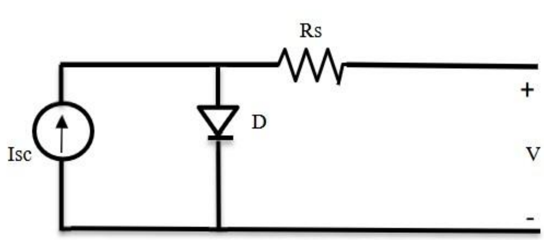


Fig. 2: Equivalent model for photovoltaic array.

Fig. 2 depicts fundamental equivalent model, which properly captures. The current-to-voltage (I-V) characteristic curve of a solar photovoltaic cell or panel. The P-V and I-V characteristic curves as shown in Fig.3, illustrate three important points: the *Voc* (open circuit voltage) point, the *Vmp*, *Imp* (maximum power) point, and the *Isc* (short circuit current) point.

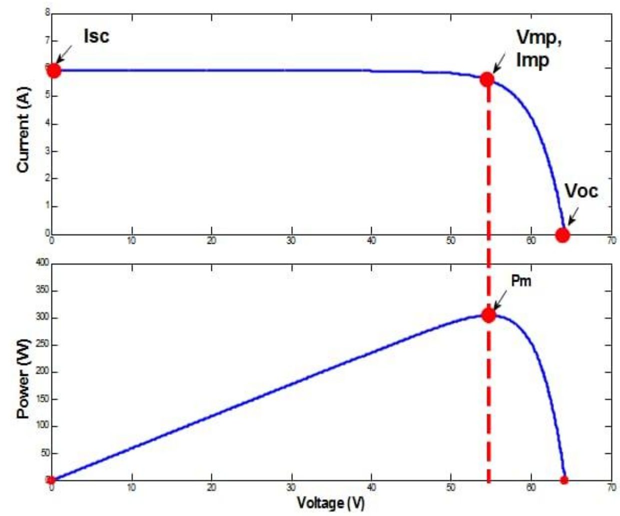


Fig. 3: Features associated with a photo voltaic array, I-V and P-V.

2.2 Solar Peak Power Tracking controller

In the Framework of standalone photovoltaic-fed EV charging setup, the MPPT algorithm shown in Fig.4, determines, optimal duty cycle for gating to maximize PV array's power output.

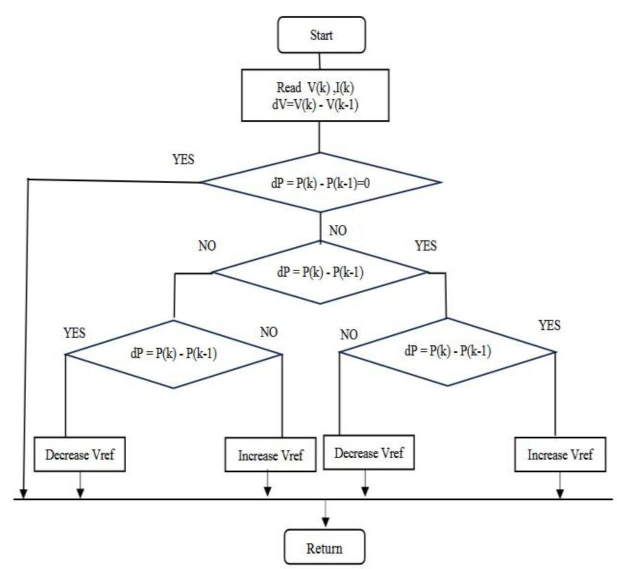


Fig. 4: Hill climbing method (P & O) flow chart.

However, to ensure stable and smooth power regulation, a PI controller is implemented at the MPPT output, refining the duty cycle by minimizing errors and reducing fluctuations. The corrected duty cycle is then fed into a PWM generator, which produces high-frequency gating pulses for those switches providing electricity to the Boost, SEPIC, or Interleaved Boost Converter. This controlled switching ensures efficient voltage regulation and stable power delivery to the EV battery. By integrating MPPT, PI control, and PWM-based switching, the system enhances energy efficiency, improves battery charging stability, and ensures reliable operation under varying environmental conditions. The converters analysis is presented below.

2.3 Converters

2.3.1 Boost Converter

Stepping up *Vin* (input) for a higher *Vdc* (output voltage) is an efficient method of dc/dc switching converter operations. This voltage conversion occurs during the switch is on, the energy would store in an inductor, and when the switch is off, then it releases for the load as shown in Fig. 5.

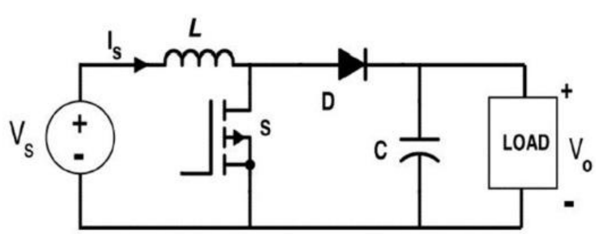


Fig. 5: Boost (step-up) converter topology

2.3.2 SEPIC Converter

A DC-DC converter that can raise, lower, else retain a Vin (input) voltage is called a Single-Ended Primary-Inductor Converter (SEPIC). Capacitors, inductors, and switches are used in this switching power converter to control voltage. Applications like battery-powered devices, where the input voltage may fluctuate greatly, benefit from the SEPIC as shown in Fig. 6. Additionally, it is effective and maintains a steady voltage across a broad variety of input voltages [7].

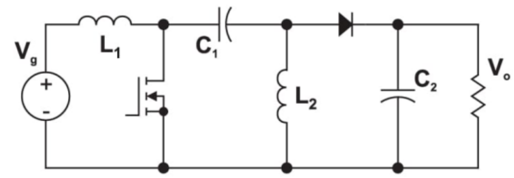


Fig. 6: DC-DC SEPIC Converter.

2.3.3 Buck-Boost Converter

One kind of DC-DC converter that can produce a voltage at the output (*Vdc*), is either higher or lower than the supply potential (*Vin*) is a continuous buck-boost conversion, making it versatile power conversion topology for various applications in power electronics where input voltage regulation and output voltage requirements may vary [12] as shown in Fig. 7.

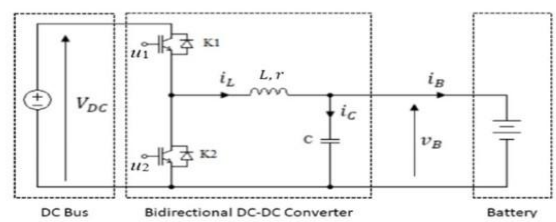


Fig. 7: DC-DC bidirectional buck boost converter topology.

2.3.4 Interleaved Boost Converter

For the particular type of Multi-phase Interleaved Step-Up Converter called an Interleaved Boost Converter (IBC) reduces supply Source of current ripple along with improves efficiency by using several parallel boost stages with phase-shifted switching as in Fig. 8. It boosts power handling capacity, lowers losses, and enhances thermal performance by dividing power among several inductors and switches. IBCs are frequently used in power factor correction, electric vehicle, and renewable energy systems. They do, however, need exact control for phase synchronization and current balancing [13].

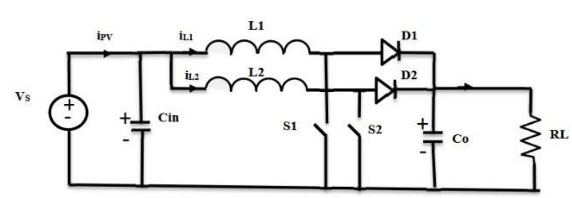


Fig. 8: Multi-phase interleaved step-up converter.

2.4 Energy Storage System

The PV array as shown in Table. 1, excess energy was contained within the Storage Setup (ESS). When electricity produced fails to produce enough for charging the automobile's electric battery during periods that have significant demand, the energy that is stored might be used to power the demands [8].

Table. 1: Energy storage system specifications

Specifications	Lead acid Battery
Energy Density	30 - 50 W h / kg
Charge/Discharge Efficiency	45 - 95 %
Specific Power(P)	180 W / kg
Cycle Durability	350 Cycles
Cell Voltage	2.1 Volts
Period(Life Span)	15 Year

2.5 Electric Vehicle Battery Charging

The EV battery charging attempts at charging directly from the photovoltaic panels as a way to minimize consumption of electricity through the electrical network. When production is halted, the Energy Storage System (ESS), which uses lithium-ion batteries, is utilized for recharging the electric automobile battery, as outlined in the features listed in Table. 2 [9].

Table. 2: Electric vehicle battery charging specifications.

Specifications	Lithium-ion Battery
Energy Density	100 - 265 Wh / kg
Charge/Discharge Efficiency	80-93 %
Specific Power	250 - 350 W / kg
Cycle Durability	500 - 1,200 Cycles
Cell Voltage	3.2 Volts
Period(Life Span)	3-5 Years

2.6 Control Techniques in Proposed System

Control techniques are essential for the suggested setup in order to handle power fluctuations, stabilize the DC bus voltage, and optimize performance as shown in Fig. 9. Key components include MPPT for PV management, a buck controller for EV charging, and a bidirectional controller for battery regulation and DC bus stability [8].

2.7 Proportional Integral Controller

Proportional-Integral (PI) controllers are essential for maintaining a stable, continuous output, such as a constant current as shown in Fig. 10.

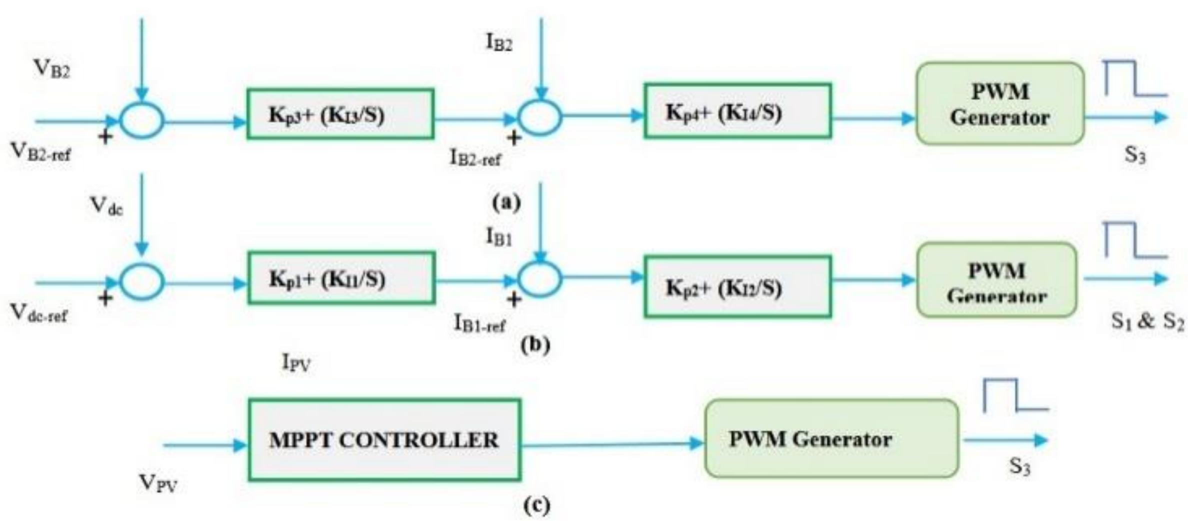


Fig. 9: Control stagey of (a) Optimal power point tracking, (b) Electric automobile charge, (c) Energy storage.

By continuously adjusting based on feedback, they ensure the output aligns with the desired target. PI controllers control battery current while charging and draining in battery management. The two way (bi-directional) converter facilitates charge/discharge operation of the battery based on the system's requirements. [10] It is done through manual tunning or Ziglar Nicholas tuning method, experimental tuning method can be summarized as follows: Start by simplifying the PI controller to its proportional component having buck controller very less amount of proportional gain, bringing the integral action to zero, so deactivating it. Make sure the controller stays inside its bounds by gradually increasing the proportional gain until the output signal shows constant oscillations. By changing the set point after every gain adjustment, one may start a disturbance and see if the loop oscillates. With an oscillation period (T_{osc}), the oscillations take place at a critical proportional gain (K_{pc}). For the PI controller, the gains for the proportional (Kp) and integral (Ki) components are defined as follows in equations (1) and (2) modified by monitoring the parameters K_{pc} and T_{osc} [11].

$$K_p = 0.35\ K_{pc} \quad (1)$$

$$K_i = 0.8\ K_p/T_{osc} \quad (2)$$

2.9 Buck Controller

In order to charge EV batteries, the Buck Converter Controller uses fixed current phase (Constant Current)/ fixed voltage phase (Constant Voltage). The charging process involves two distinct stages: first, during the Constant Current (CC) phase, a steady current is applied until the battery attains a specific voltage level then, in the Constant Voltage (CV) phase, the voltage is held constant while the current gradually decreases to complete the charging process. A Proportional-Integral (PI) Controller is utilized for regulation, with Ziegler-Nichols tuning employed to optimize the proportional (Kp) and integral (Ki) gains. Initially, Ki is set to zero, and Kp is incrementally increased until oscillations are observed. Subsequently, Ki is fine-tuned to ensure system stability. This approach ensures efficient and safe charging while avoiding overcurrent and voltage fluctuations [11].

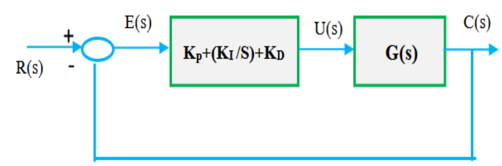


Fig. 10: PI Controller

3. Results and Analysis

The simulation circuit shown in Fig. 11, as it is modelled by using MATLAB/Simulink software. The parameters of the simulation are shown in Table. 3. The Fig. 12 represents the electric vehicle battery charging, any discrepancy between the reference voltage (*Vref*) and the actual voltage is sent through the PI controller for correction, then that produces a ref current which was contrasted once more with the current from the battery then that is given as gating pulses to buck converter.

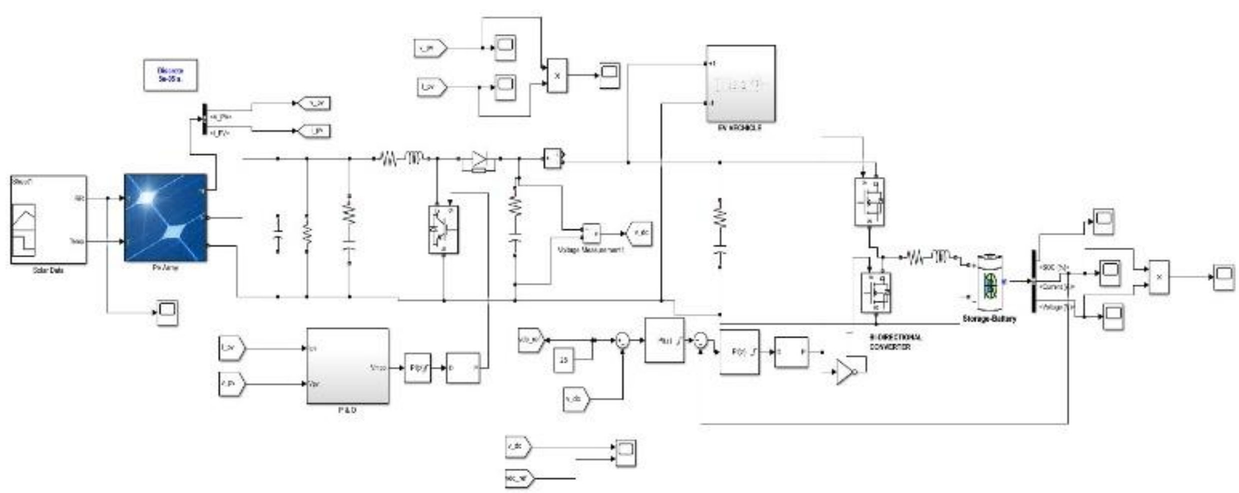


Fig. 11: Simulation circuit of standalone fed solar PV electric vehicle battery charging.

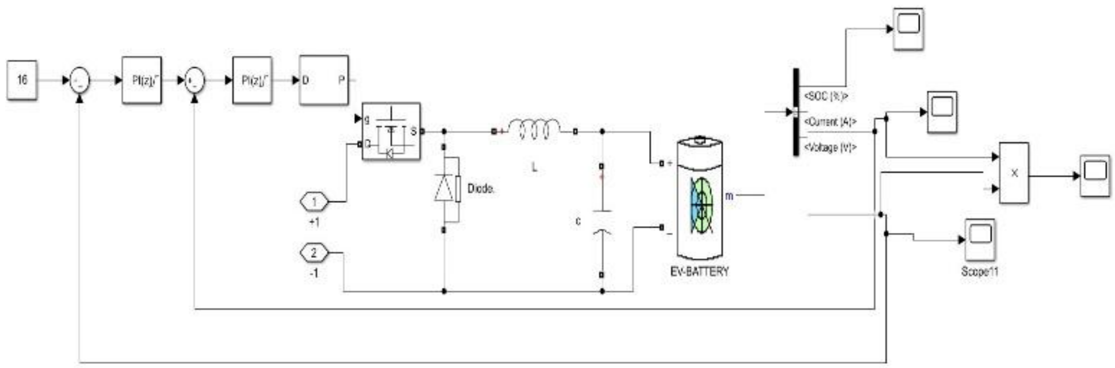


Fig. 12: EV battery charging.

Table. 3: Specifications of the Simulation model

Parameters	Values
PV	120W, 21.6V, 7.5A
DC bus voltage	25V
Charging converter Inductor	2mH
Boost Capacitor and Inductor	3.3mF, 5mH
EV & storage battery voltage	15V, 12V

Table. 4: Comparison of Boost, SEPIC & Interleaved Boost Converters.

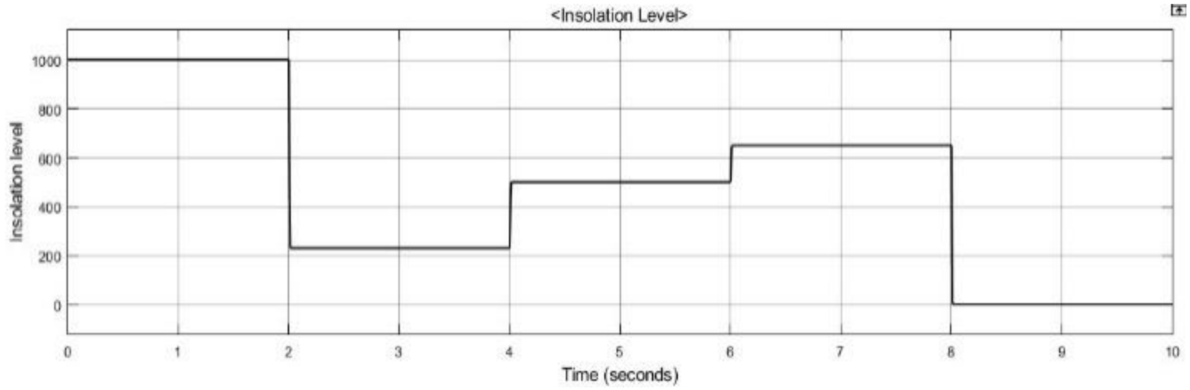
Feature	Boost Converter	SEPIC Converter	Interleaved Boost
Function	Always Step up the input Vin	Either Step up or step down the input Vin	Always Step up the input Vin
Output Voltage	Always higher than input	Either higher or lower	Always higher than input
Topology	Single inductor, single switch	2 inductors & 2 Capacitors	Two parallel boost converters with phased-shifted operations.
Complexity	Simple and more efficient	More complex than boost	More complex and efficient than boost.
Efficiency	Higher efficiency for boosting voltage	Lower than boost due to additional components	Higher than both Boost and Sepic.
Applications	Solar chargers and electric vehicles	Battery-powered systems	High power applications

The Comparison of Boost, SEPIC & Interleaved Boost Converters is presented in Table. 4.

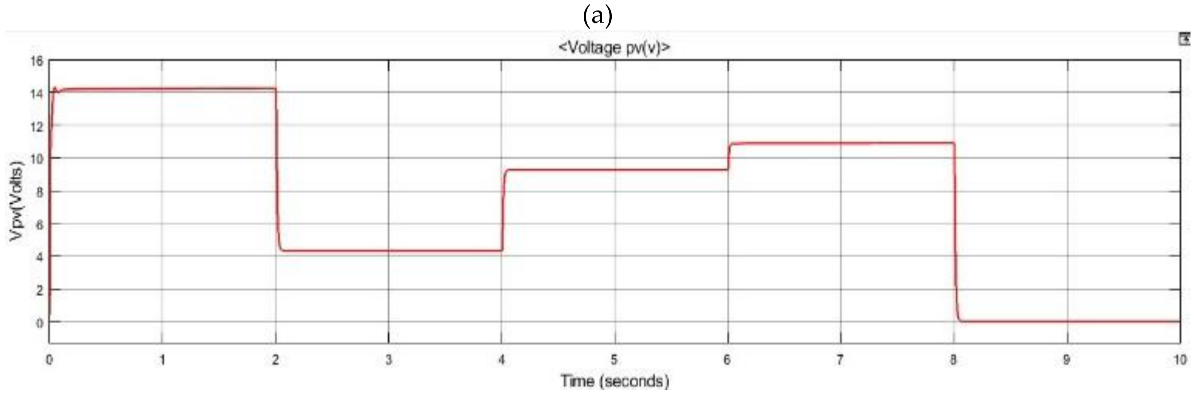
4. Outcomes

Fig 13 (a) depicts the insolation level of the photovoltaic array, which absorbs energy from the sun during the day and stores it for later use. Similarly, Fig. 13 (b) depicts potential at the photovoltaic array, along with Fig. 13 (c) depicting current towards the photovoltaic array, which follows the characteristics of solar energy insolation.

The o/p voltage level (*Vdc*) displayed in the Fig. 14, with reference voltage (*Vref*) are also mentioned in comparison for boost converters in replacement of SEPIC and Interleaved boost converters. Fig. 14 (a), Fig. 14 (b) and Fig. 14 (c) illustrate the boost converter, SEPIC converter & Interleaved Boost converter, respectively. For the SEPIC they provide step-up/down capability but have higher ripple and lower efficiency. Boost converters are more efficient than SEPIC but suffer from increased ripple at high duty cycles. In comparison, interleaved will provide higher efficiency with lower ripple than boost and SEPIC. The electric vehicle battery output performance of boost converter is displayed in Fig. 15. The SOC of EV battery is continuously rising, but there would be fluctuations in the current as shown in Fig. 15 (b) such that the output power also contains the fluctuations. Which can be overcome by the SEPIC Converter below. Both fluctuations and efficiency can be overcome by an interleaved boost. The SEPIC converter performance can be observed below Fig. 16, the fluctuations present over the current output, boost can be reduced but the efficiency is less when compared with the boost conversion. In Fig. 16 (b) displayed in the form of stable current of the battery without fluctuations.



(a)



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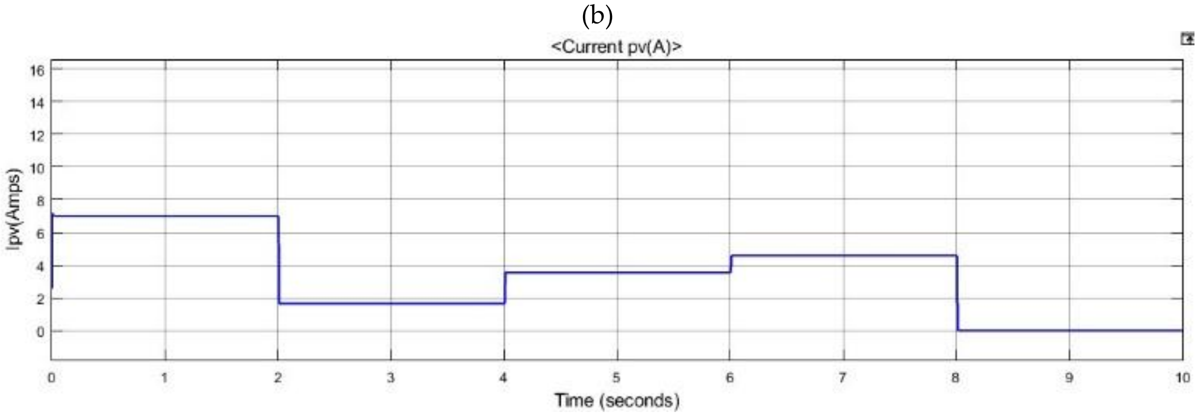
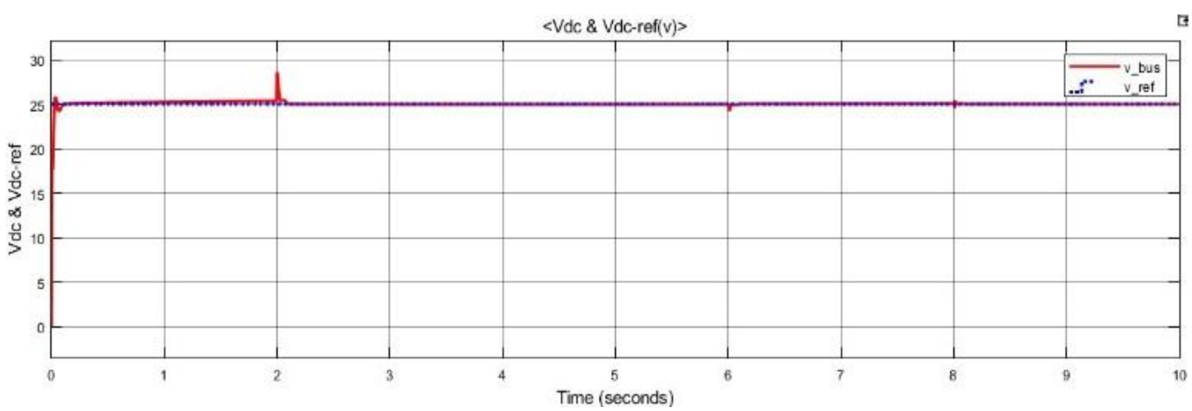


(c)

Fig. 13: Performance (a) Photovoltaic insolation level, (b) Photovoltaic voltage, (c) Photovoltaic current level.



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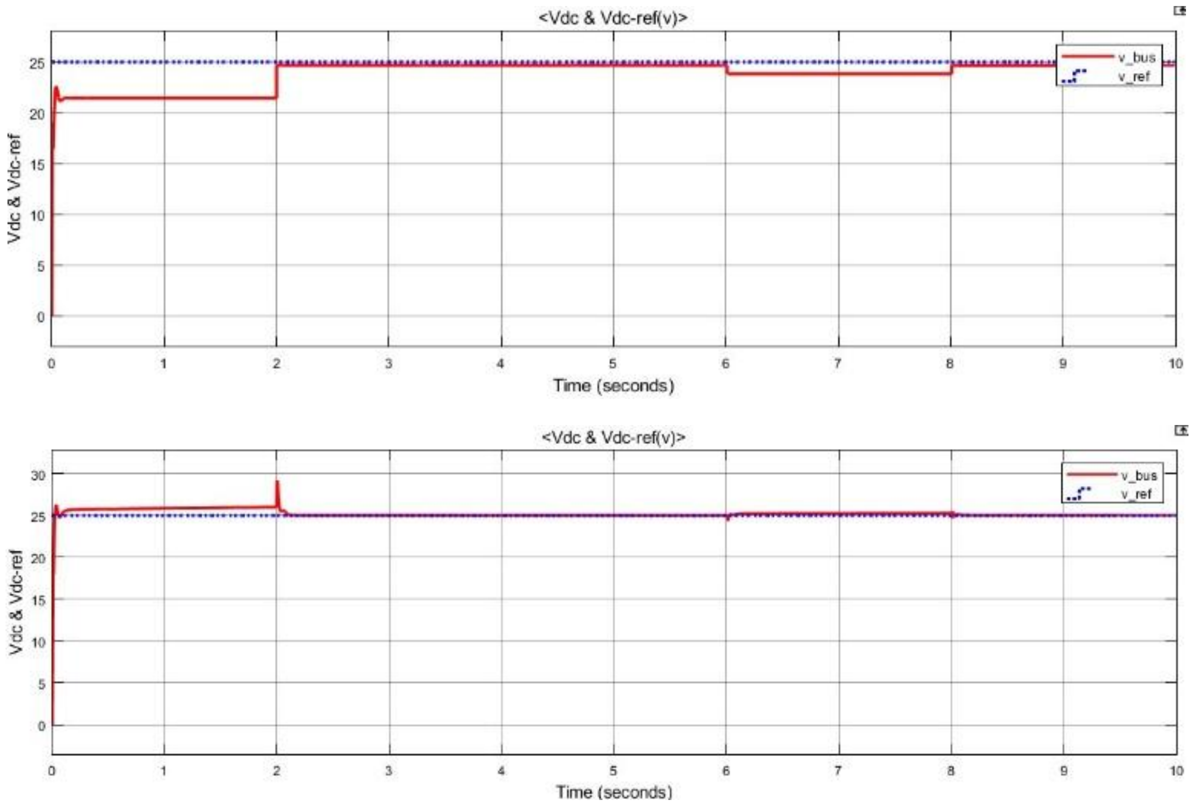
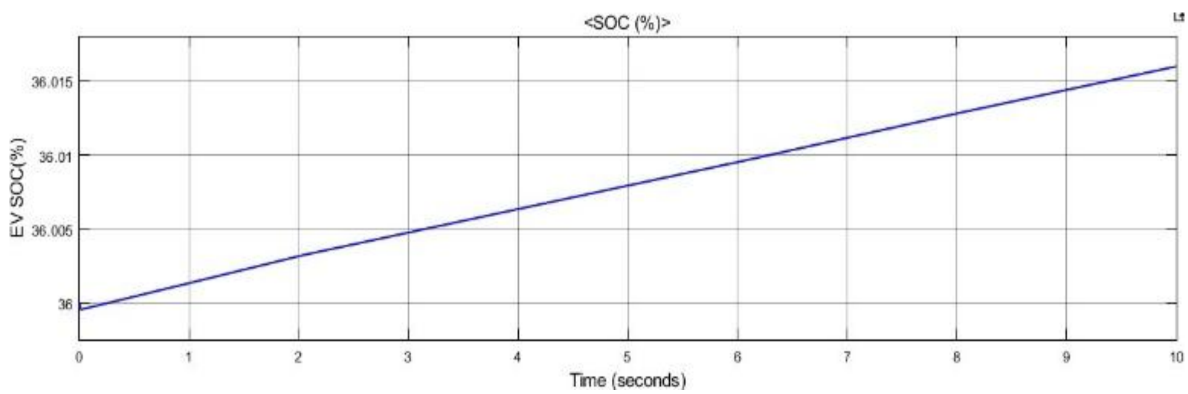


Fig. 14: (a) Boost converter DC bus voltage, (b) SEPIC converter DC bus voltage, (c) Interleaved boost converter DC bus voltage.



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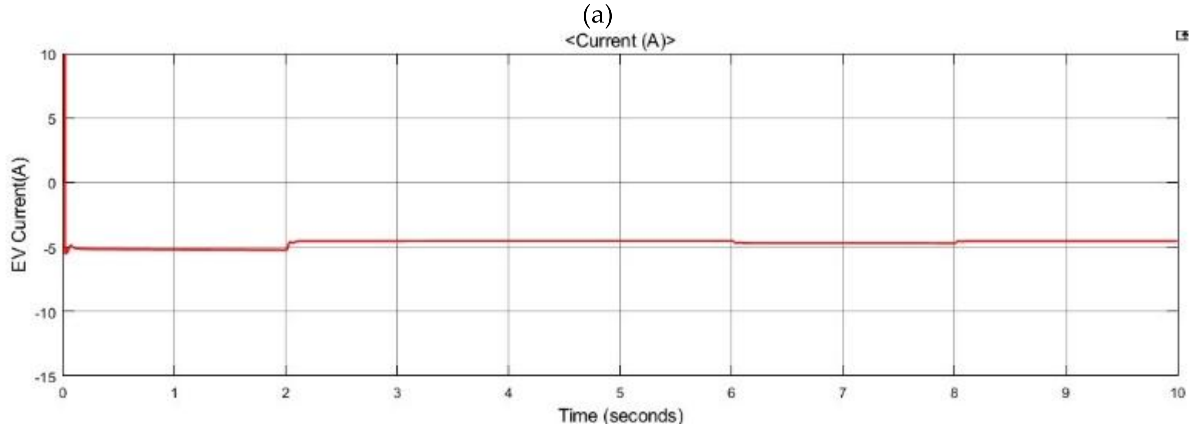

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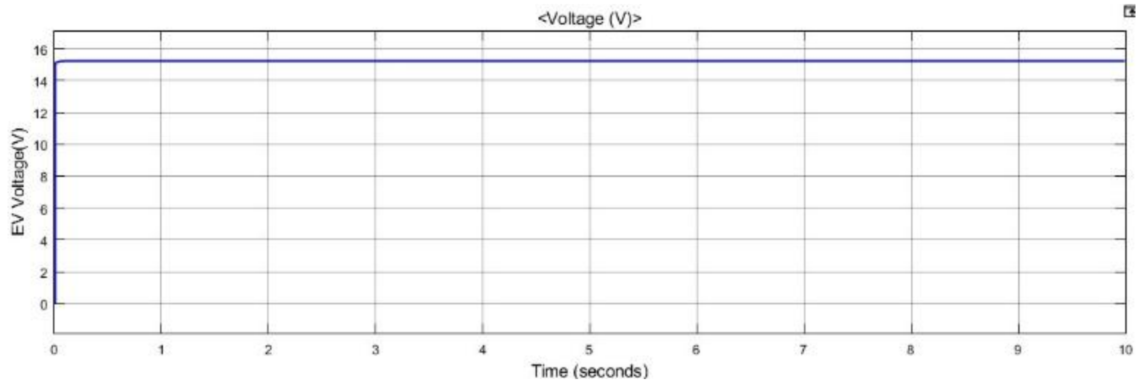
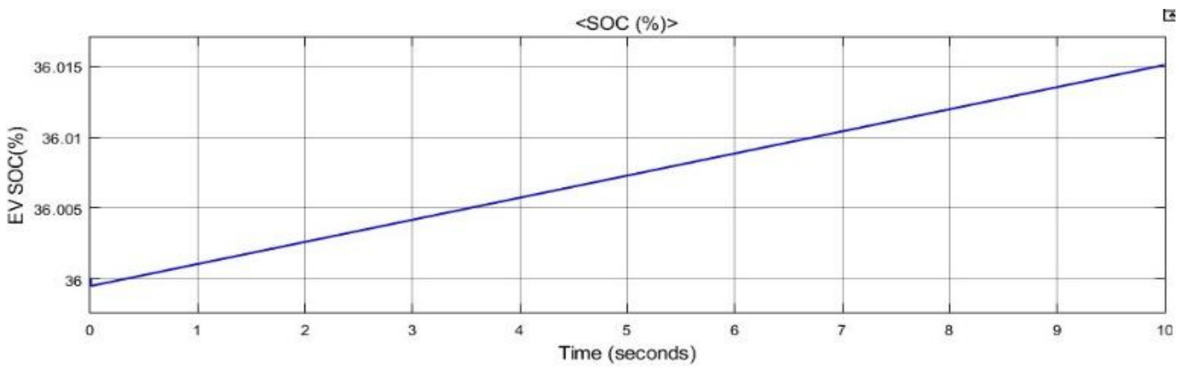


Fig. 15: Boost converter performance (a) Electric vehicle battery state-of-charge, (b) Current flowing through battery, along with (c) Voltage level for the battery.



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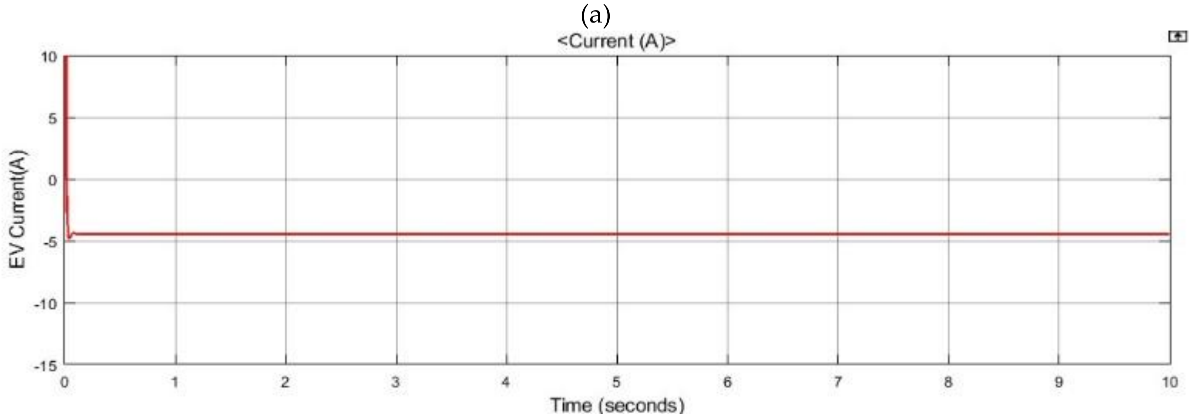

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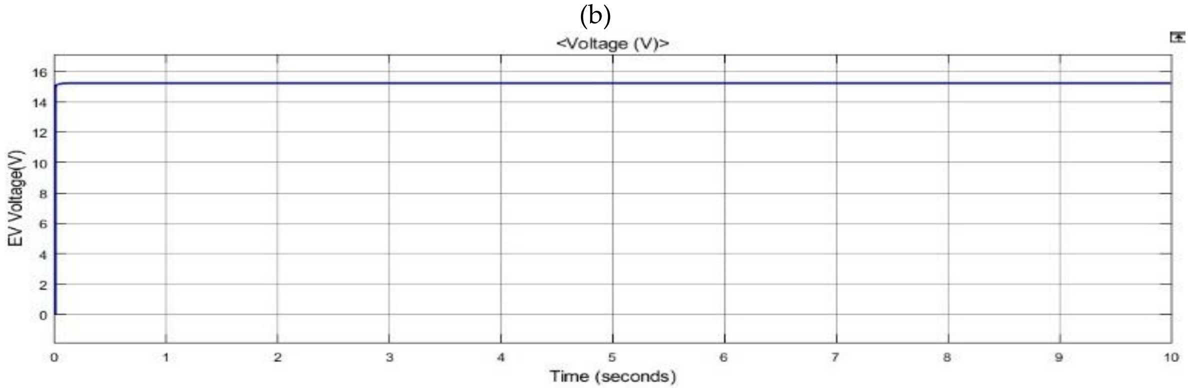
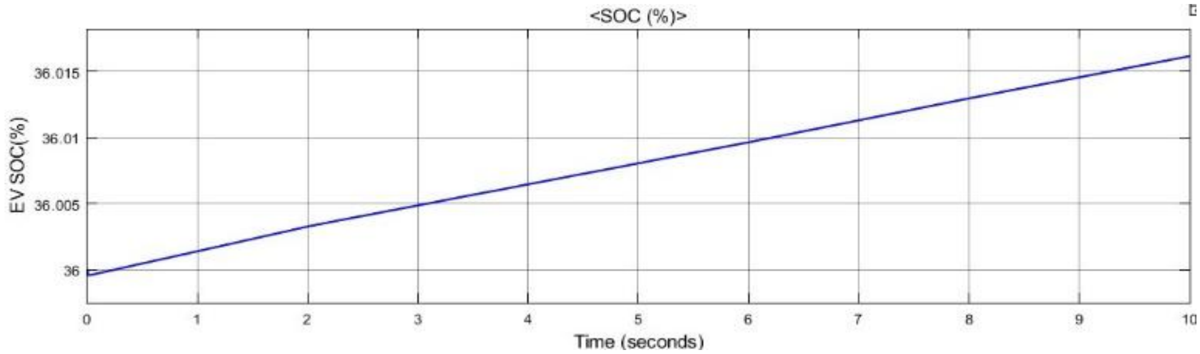


(c)

Fig. 16: SEPIC Converter performance (a) Electric vehicle battery state-of-charge, (b) Current flowing through battery, along with (c) Voltage level for the battery.



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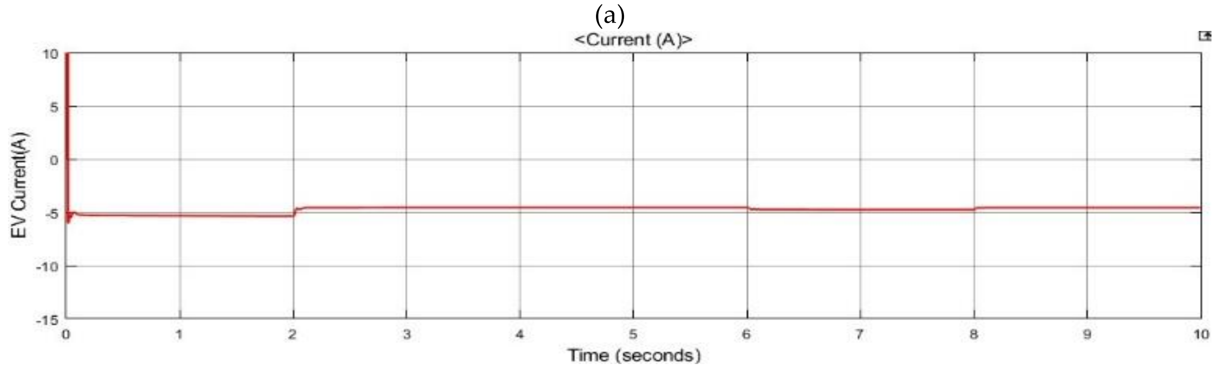

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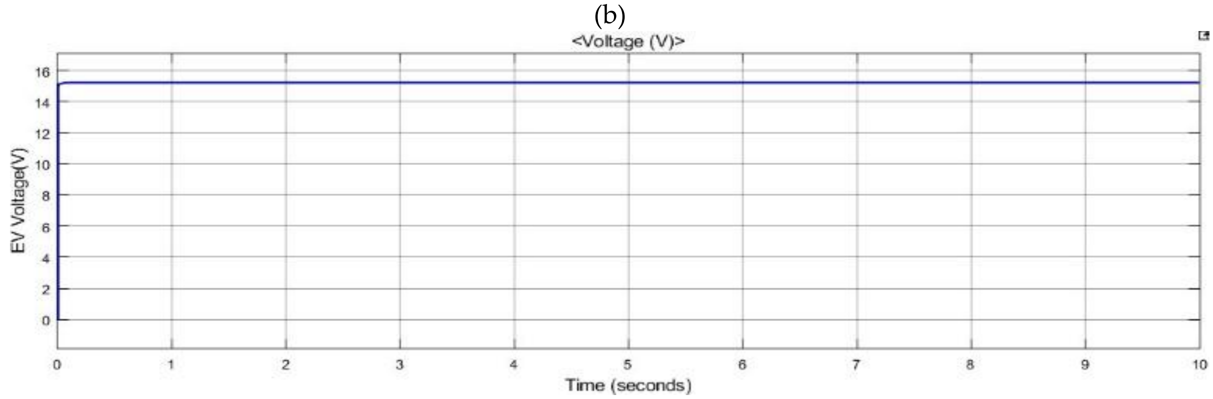

(c)

Fig. 17: Interleaved boost converter performance (a) Electric vehicle battery state-of-charge, (b) Current flowing through battery, (c) Voltage level for the battery.

The Interleaved Boost converter performance can be observed below Fig. 17, the fluctuations present over the current output, boost can be reduced and the efficiency is higher when compared with the boost and SEPIC converter. Fig. 17 (b) shows the stable current of the battery without fluctuations.in comparison with SEPIC, which produces reduced current ripple.

5. Conclusion

This paper models an off-grid photovoltaic electric vehicle battery charging system that relies solely on solar energy for continuous power supply. It focuses on using key components like the Maximum Power Point Tracking (MPPT) controller, PI controller, and buck converter, which play crucial roles in ensuring system efficiency. Additionally, the study replaces the power converter with a SEPIC to reduce current ripple, enhancing the system's performance and Interleaved Boost converter, which is more efficient than both unidirectional (Boost) and SEPIC converters. The outcomes are analyzed, and a detailed comparison is provided, highlighting the efficacy of the proposed approach in charging electric vehicles.

Conflict of interest

The authors declared ‘No conflict of interest’.

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