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Evaluation of PV-based Buck-Boost and SEPIC Converters for EV Charging Applications

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In recent decades, environmental issues have become an area of greatest concern due to changes in global climate conditions. The transportation sector is a major contributor to carbon dioxide emissions, accounting for more than 22.9% of total carbon dioxide emissions. At present, most vehicles run on gasoline/diesel as fuel which is unsustainable and unviable as fossil fuels produce carbon emissions and fuel costs are rising. To address these issues, electric vehicles (EVs) offer an attractive solution as alternative to internal combustion engine vehicles that use electricity as an energy source. It is logical to use renewable energy to charge vehicles, which makes renewable energy an end-to-end clean energy source. In electric vehicles, energy conversion plays an important role. In the energy conversion process, alternating current (AC) can be converted to direct current (DC), or direct current can be converted to alternating current. In EV fast charging applications, DC-to-DC conversion is used, which requires DC-to-DC converters. In this paper, a detailed evaluation of the Buck-Boost and Single-Ended Primary Inductance Converters (SEPIC) with PV as input is analyzed for EV charging applications to make it end-to-end clean energy. For this purpose, a 5-by-5 PV system with a Buck-Boost, SEPIC converters with particle swarm optimization technique is considered, which is simulated in a MATLAB/SIMULINK environment. The simulation results showed that the ripples in output are minimal in SEPIC which supports the smooth and efficient charging of EV battery.

Keywords: Solar PV system; DC-DC converters; Particle Swarm Optimization (PSO); Electrical Vehicles; Optimization

Introduction

Power electronic converters play a vital in photovoltaic (PV) applications by aiding efficient conversion, control, and management of the electrical energy produced by solar panels [1, 2]. Solar modules generate different voltage and current levels depending on environmental conditions such as sunlight and temperature. Solar module power is typically in the form of direct current (DC) at low voltage levels [3]. Grid-connected inverters, or power electronic converters, convert the direct current generated by the solar modules into grid-compatible alternating current (AC) [4]. These inverters also provide synchronization, voltage regulation, and control functions to ensure safe and reliable integration of photovoltaic systems into the grid. Power electronic converters in

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grid-connected PV systems can also provide reactive power control. By controlling the inverter power, you can regulate the flow of reactive power into and out of the grid [5]. Power electronic converters play a key role in photovoltaic systems that are integrated with energy storage systems such as batteries [6]. These converters allow efficient charging and discharging of batteries, voltage regulation, and synchronization with the grid [7]. Overall, power electronic converters play a critical role in PV applications by optimizing power generation, enabling grid integration, facilitating energy storage, and ensuring system protection and security [8].

Operation of Buck-Boost Converter

Buck – Boost converter is a combination of both buck and boost converters. The advantages of both buck and boost converters are embedded in the buck-boost converter. The advantage of using a buck/boost converter is that it can step up or down the input voltage, making it suitable for a wide range of applications. The buck-boost converter provides lower duty cycles and higher efficiency over a wide range of input and output voltages. Buck-boost converters are widely used in a variety of applications including battery-powered devices to extend battery life. These are also suitable for solar power systems to regulate voltage levels and maximize power output. Buck-boost converters are used in LED lighting systems to regulate voltage levels and maintain constant current. This converter can be used in applications where constant voltage is required.

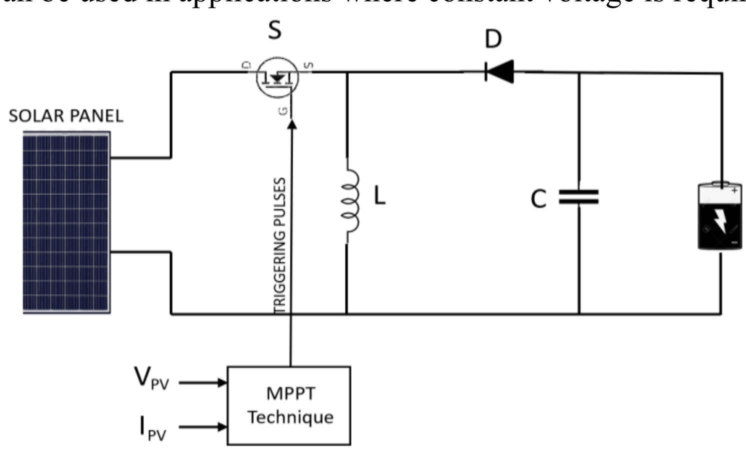

Figure 1. Basic circuit diagram of Buck-Boost converter

When the switch (MOSFET) is turned on, the power supply current begins to flow through the switch, through the inductor, and back to the power supply as shown in Fig. 1.

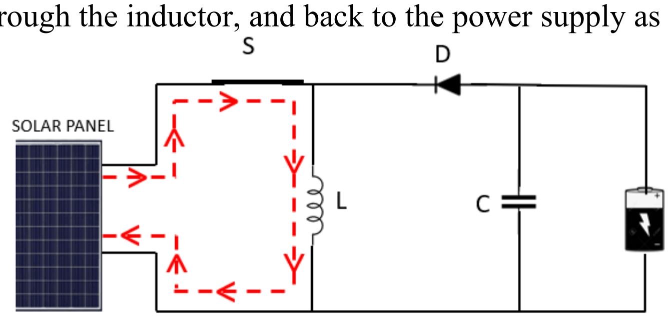

Figure 2. Mode 1 operation of Buck-Boost converter

The diode (D) is reverse-biased and acts as an open switch, isolating the load from the supply current. When the power supply energizes the inductor, the inductor starts charging with the polarity shown in Fig. 2.

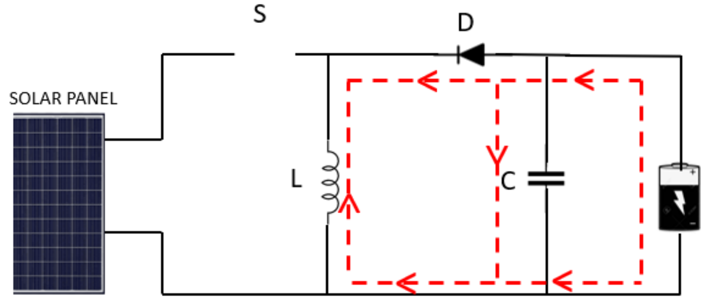

Figure 3. Mode 2 operation of Buck-Boost converter

When the switch is off, the reduction in inductor current creates a negative voltage across the inductor. The current that flowed through the switch and inductor in the previous interval flows through the inductor, capacitor, load, diode, and back to the inductor, as shown in Fig. 3. The inductor continues to discharge and the inductor current decreases until the MOSFET turns on again in the next cycle.

$$V_o = \frac{D}{1-D} V_i \quad (1)$$

Therefore, from the above equation (1), the output voltage depends on the duty cycle. If the duty cycle (D) is greater than 0.5, the circuit operates as a boost converter or boost DC converter.

Operation of SEPIC Converter

SEPIC is abbreviated as a single-ended primary inductance converter. It is a type of DC-DC converter that enables a DC voltage range on the input side and provides a stable voltage on the output side. This type of converter is very similar to buck-boost converters and Cuk converters which provide an output voltage greater than, less than, or equal to the input voltage.

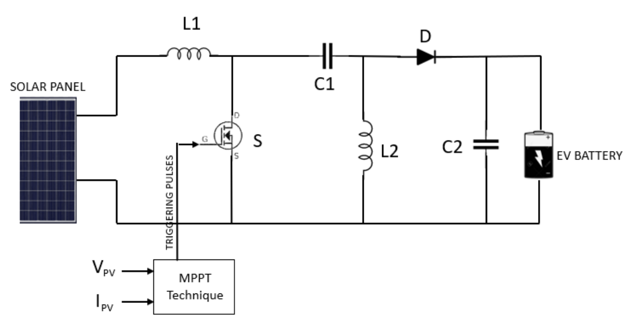

Figure 4. Basic circuit diagram of SEPIC converter

The basic circuit diagram consists of a Switch "S", two inductors (L_1, L_2), two capacitors (C_1, C_2), and one Diode. A switch is a semiconductor device, in the SEPIC converter generally a transistor (MOSFET, IGBT, or BJT) is used as shown in Fig. 4.

MOSFETs are preferred over IGBTs and BJTs in most DC/DC converters because of their high input impedance and low voltage drop.

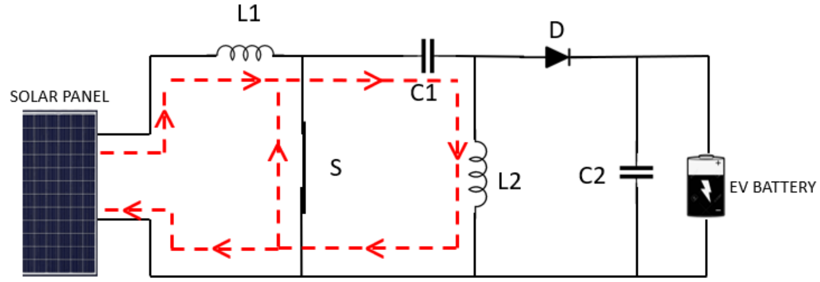

Figure 5. Mode 1 operation of SEPIC Converter

Initially the switch "S" is closed and the current from the source will pass through the switch, inductor L_1, and back to the source as shown in Fig. 5. This will cause an increase in the inductor's current, I_{L1}, which will start charging from the input source. During this charging process, the inductor's instantaneous voltage, V, will be approximately equal to the source voltage, V. Moreover, when the Switch "S" is on, the energy released by capacitor C1 will charge the inductor L_2. Through the Switch "S", the capacitor C_1 will release its energy to the inductor L_2.

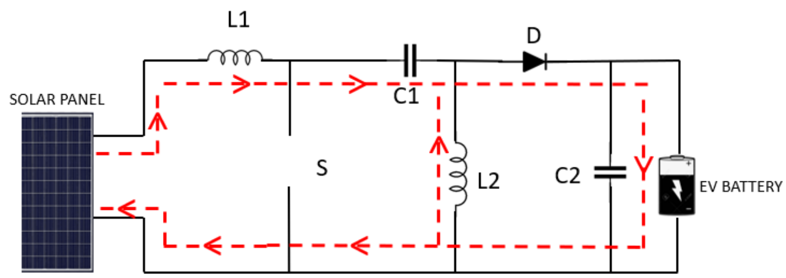

Figure 6. Mode 2 operation of SEPIC Converter

After the Switch "S" is turned off, the inductor L_1 reverses polarity and discharges to capacitor C_1. The charged inductor L_2 then discharges, forward-biasing the diode and transferring energy to the load as shown in Fig. 6. When the Switch "S" is turned on again, the cycle repeats.

The switching or triggering pulses for the switches are given through the particle swarm optimization algorithm. Population-based stochastic optimization (PSO) is a technique introduced by James Kennedy and Russell C [9]. PSO-based tracking systems do not require differential calculations, have a small number of tuning parameters, are system-independent, and have a high probability of finding an overall optimal solution with high computational efficiency [10]. The particles are randomly initialized and start to move in a given search space with a certain velocity. Then, for each iteration, a new velocity value is calculated based on the current velocity, the previous best position and the global best position. During this optimization process, the agents are spread over the search space in different directions.

$$v_i^{k+1} = wv_i^k + c_1 r_1 \{P_{\text{best}\,i} - x_i^k\} + c_2 r_2 \{G_{\text{best}} - x_i^k\} \tag{2}$$

and the position of i^{th} particle X_i is adjusted using the below equation.

$$x_i^{k+1} = x_i^k + v_i^{k+1} \tag{3}$$

Here, w is the inertia weight, c_1 and c_2 are the acceleration coefficients, r_1 and r_2 are random numbers in the range (0 –1), P_{besti} is the personal best position of particle i, and G_{best} is the best position of the particles. Equations 2 and 3 are called flight equations and show that the new position of each particle is affected by three terms. The first term, inertia weight ω, is the current velocity of the particle. The second term, weighted by cognitive acceleration coefficient c_1, prompts the attraction of the particle toward its own personal best (cognition influence), and the third term, weighted by social acceleration coefficient c_2, prompts the attraction of the particle toward the global best (social influence). The personal best position P_{besti} is updated using Equation 4 if the condition in Equation 5 is satisfied, that is,

$$P_{\text{best}_i} = x_i^k, \tag{4}$$

$$f(x_i^k) > f(P_{\text{best}_i}) \tag{5}$$

where f is the objective function

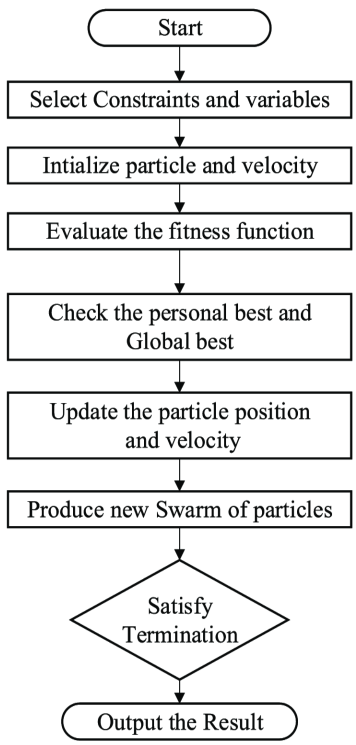

Figure 7. Flowchart of PSO method

Design of Buck-Boost and SEPIC Converters:

The operation of Buck-Boost and SEPIC are discussed in the previous section and the circuit diagram is simulated in MATLAB/Simulink environment with renewable energy as input in this case solar power as input. The triggering pulses are given to the switch by using the particle swarm optimization technique. Here a 5 by 5 PV system and the output of the PV system are connected to both the converter and the simulation diagrams are shown in Fig. 8 and 9. The output of the converters are connected to the EV battery. The simulation diagram is shown in Fig. 8.

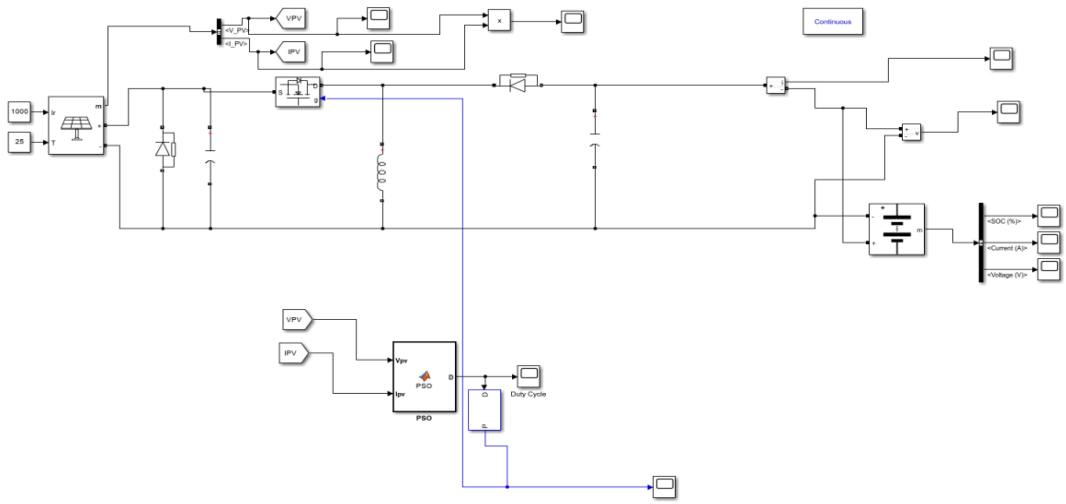

Figure 8. Simulink model of PV based Buck Boost converter

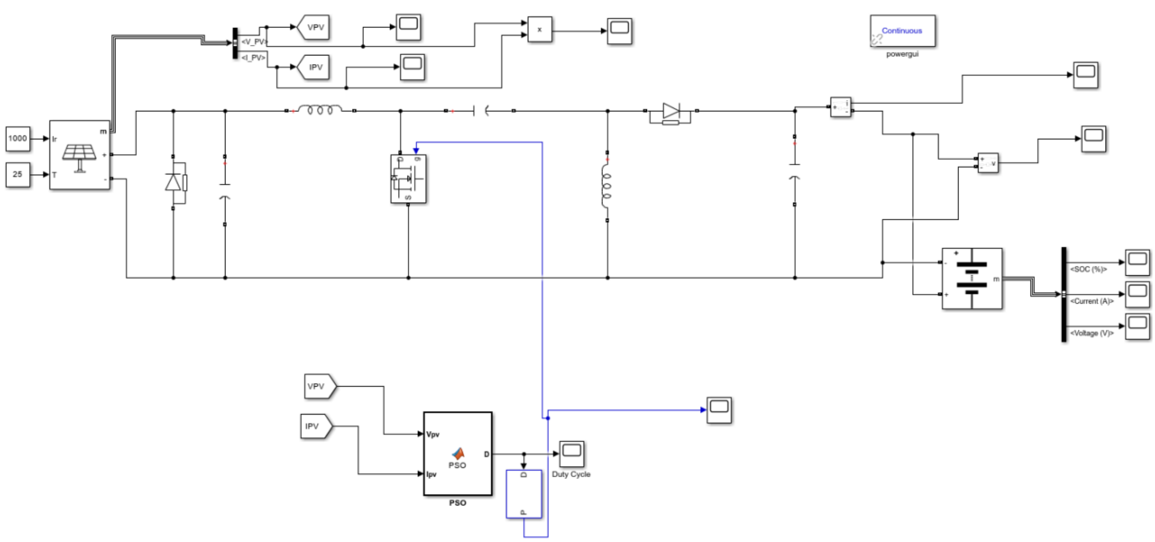

Figure 9. Simulink model of PV based SEPIC converter

The simulation parameters considered and the characteristics of the PV system are shown in Fig. 8.

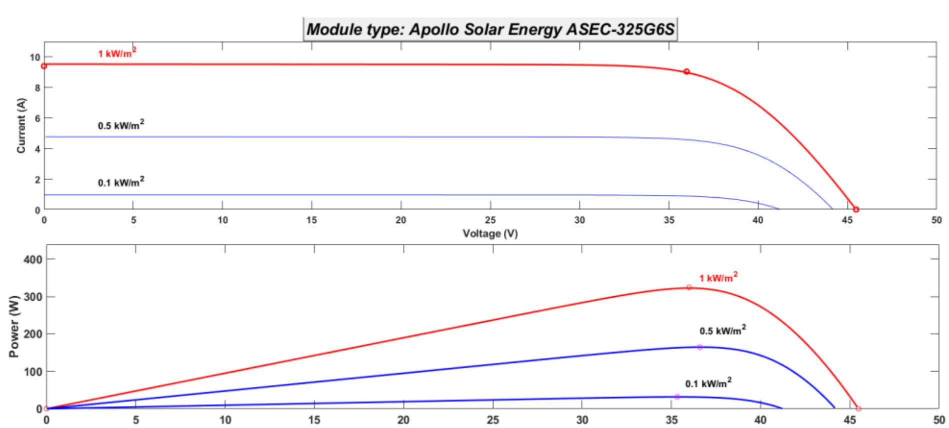

Figure 10. PV and IV characteristics of solar PV panel

and Buck-boost and SEPIC converter parameters are shown in Table 1.

Table 1. Parameter Specifications

Parameter	BUCK – BOOST Values	SEPIC Values
L1	9.77mH	34.7μH
L2	-	41.04μH
C1	44.045μF	10.55μF
C2	-	44.453μF
Battery voltage	48 V	48 V
Battery SOC	50%	50%
Switching Frequency	10kHz	10kHz

The triggering pulses for buck-boost and SEPIC converters are shown in Fig.9.

Results and Discussion

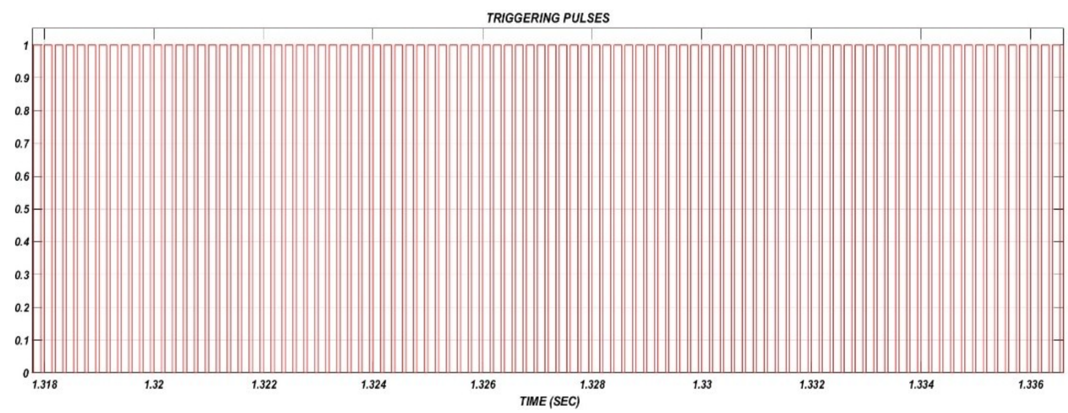

Figure 11. Triggering pulses to the Buck-Boost converter

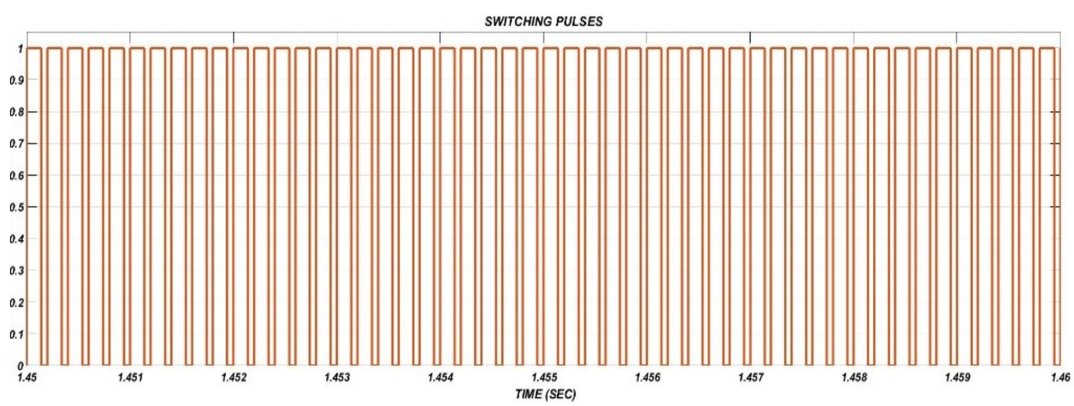

Figure 12. Triggering pulses to the SEPIC Converter

Figures 9 and 10 are the switching pulses given to the Switch 'S'. The switching pulses are generated by using the particle swarm optimization algorithm shown in Fig. 7. The switching frequency considered for calculation is 10 kHz.

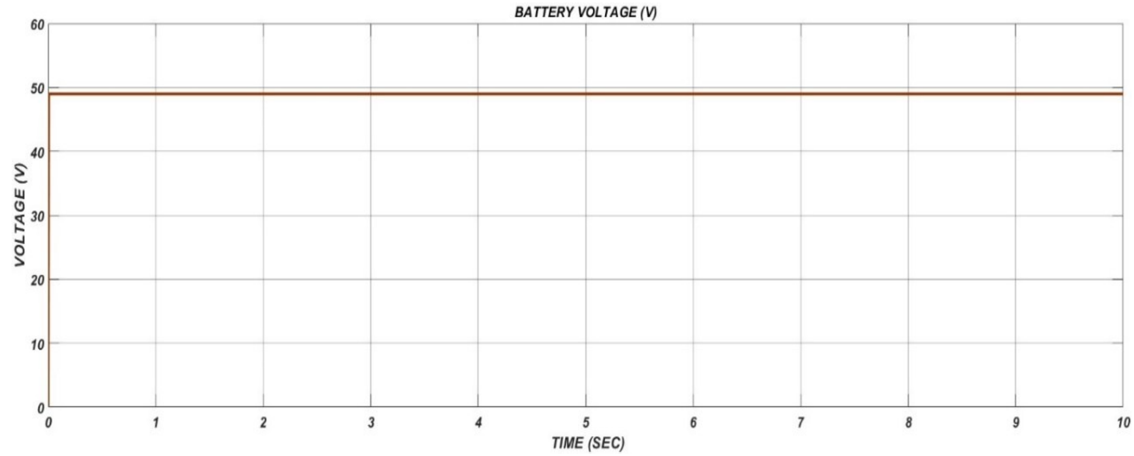

Figure 13. Battery Voltage of Buck Boost Converter

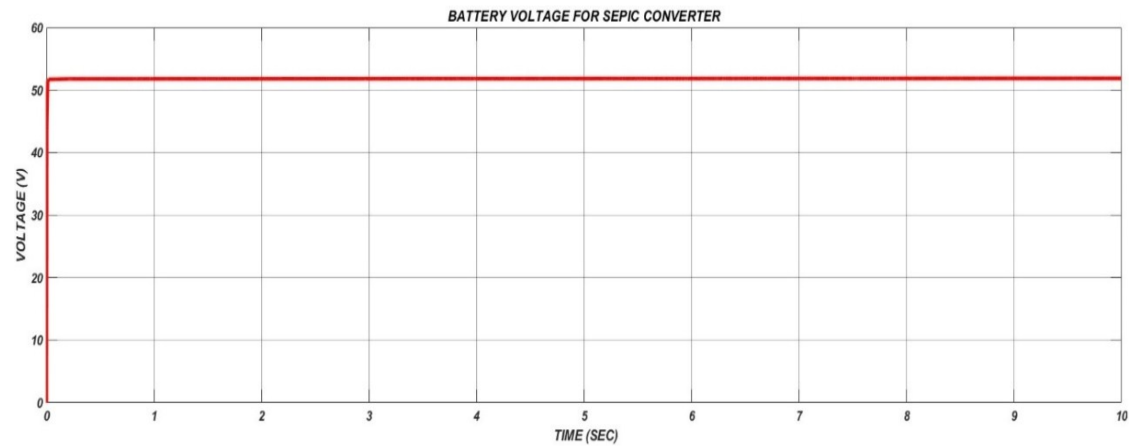

Figure 14. Battery Voltage of SEPIC Converter

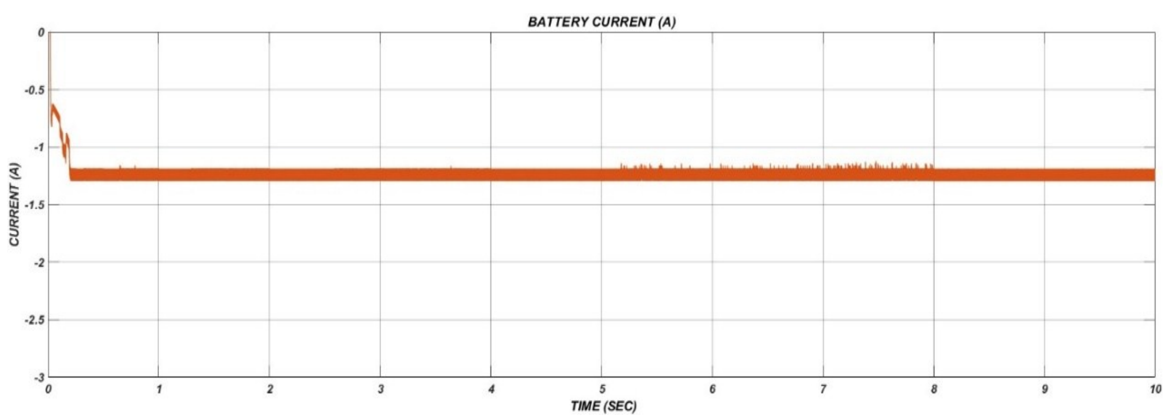

Figure 15. Battery Current in Buck Boost Converter

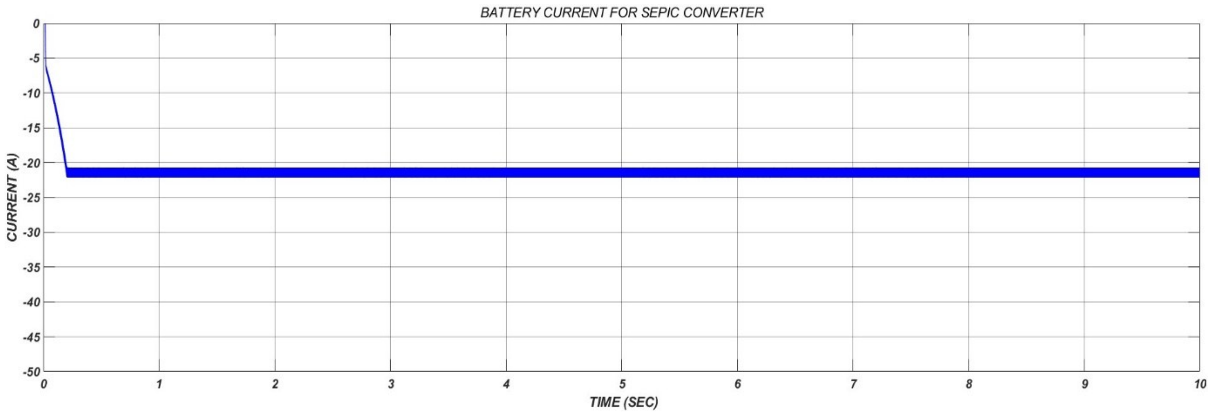

Figure 16. Battery Current in SEPIC Converter

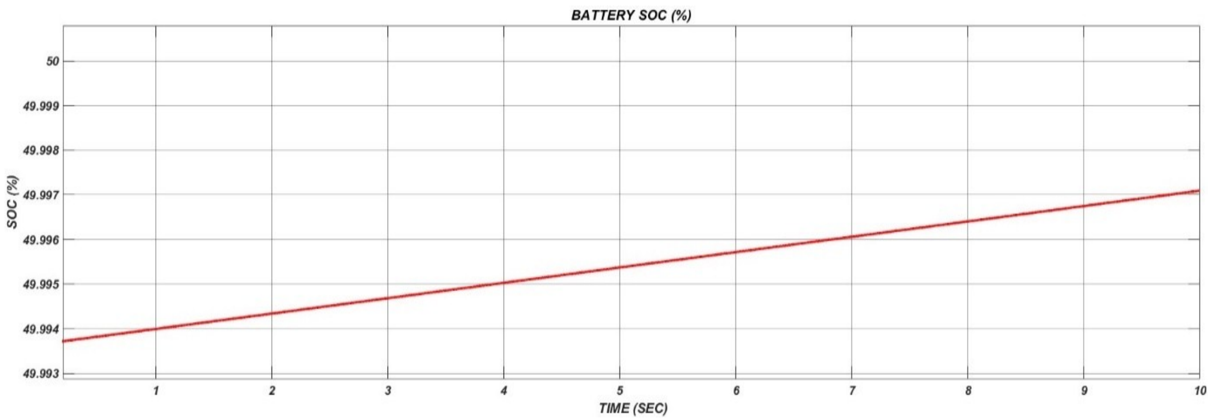

Figure 17. Battery state of charge (SOC) in Buck Boost Converter

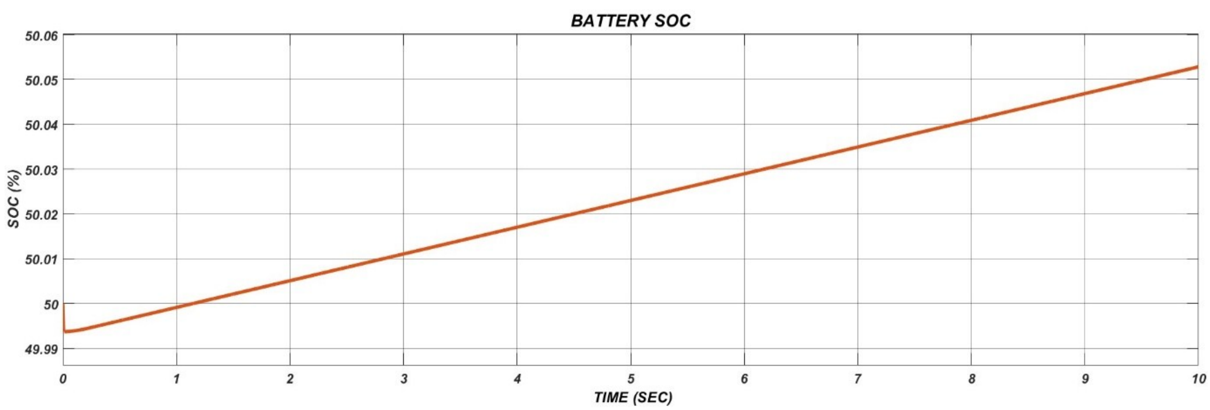

Figure 18. Battery state of charge (SOC) in SEPIC Converter

Figs. 11, 13, 15, and 17 show the battery voltage, current, and state of charge (SOC) for the buck-boost converter, while Figs. 12, 14, 16, and 18 show the same for the SEPIC converter.

Table 1. Performance Parameter

PARAMETER	Buck - Boost	SEPIC
Output Voltage (V)	48V	51V
Charging Current (A)	-1.25A	-23A
State of Charge (SOC) (%)	49.997%	50.057%

From Table 2, although the battery voltage is almost the same for both converters, the current delivered by the converters is different. The SEPIC converter delivers -23 amps of current for charging the battery, while the buck-boost converter delivers -1.35 amps. During charging, the battery draws current from the source, so the battery current is negative. The SOC of the battery gradually increases in both cases, but the charging time taken for the SEPIC converter to charge fully is approximately 8 Hrs, and for the buck-boost converter is approximately 6 Hrs. This shows that the charging is faster in the case of the SEPIC converter compared to the buck-boost converter. Based on the tabulated results, the SEPIC converter produces more current with solar power as input and is more efficient in charging the EV battery.

CONCLUSIONS

A PV-based charging mechanism for an EV using a Buck-Boost and SEPIC converters with PSO MPPT is simulated in MATLAB/ SIMULINK environment and the results are studied. From the simulation results, it is observed that SEPIC provides more current and more State of Charge (SOC) of the EV battery compared to Buck Boost. Charging time is approximately 6 hours for a SEPIC converter and approximately 8 hours for a buck-boost converter. This shows that the SEPIC converter charges faster compared to the buck-boost converter. Therefore, the SEPIC converter with solar power as input is more efficient in charging the EV battery when compared to Buck-Boost. This charging system uses solar power to charge EV batteries which makes it an end-to-end clean energy.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this paper.

REFERENCES

[1] Suryoatmojo, H., Dilianto, I., Suwito, Mardiyanto, R., Setijadi, E., & Riawan, D. C. (2018, 11-12 May 2018). *Design and analysis of high gain modified SEPIC converter for photovoltaic applications.* Paper presented at the 2018 IEEE International Conference on Innovative Research and Development (ICIRD), pp. 1-6. doi: https://doi.org/10.1109/ICIRD.2018.8376319

[2] Azer, P., & Emadi, A. (2020). Generalized State Space Average Model for Multi-Phase Interleaved Buck, Boost and Buck-Boost DC-DC Converters: Transient, Steady-State and Switching Dynamics. *IEEE Access, 8*, 77735-77745. doi: https://doi.org/10.1109/ACCESS.2020.2987277

[3] Reddy, B. V., & Chengaiah, C. (2023, 22-24 Feb. 2023). *A Modified P&O Technique for Solar based EV Charging with SEPIC.* Paper presented at the 2023 Fifth International Conference on Electrical, Computer and Communication Technologies (ICECCT), pp. 1-4. doi: https://doi.org/10.1109/ICECCT56650.2023.10179607.

[4] Kanhav, K. A., & Chaudhari, M. A. (2017). *A bidirectional multiport dc-dc converter topology for hybrid energy system.* Paper presented at the 2017 International Conference on Energy, Communication, Data Analytics and Soft Computing (ICECDS), pp. 3427-3432. doi: https://doi.org/10.1109/ICECDS.2017.8390097.

[5] Jagadeesh, K., & Chengaiah, C. (2022). A comprehensive review-Partial shading issues in PV system. In *AIP Conference Proceedings* (Vol. 2640, No. 1). AIP Publishing. doi: https://doi.org/10.1063/5.0112913

[6] Soedibyo, Amri, B., & Ashari, M. (2015). *The comparative study of Buck-boost, Cuk, Sepic and Zeta converters for maximum power point tracking photovoltaic using P&O method.* Paper presented at the 2015 2nd International Conference on Information Technology, Computer, and Electrical Engineering (ICITACEE), pp. 327-332, doi: https://doi.org/10.1109/ICITACEE.2015.7437823

[7] Mitra, A., Bhowmik, S., Mukherjee, S., Dutta, P., Banerjee, K., & Sarkar, S. (2022). *Performance Comparison and Design of Passive Components for DC-DC Buck-Boost, Cuk and Sepic Converter.* Paper presented at the 2022 IEEE International Conference of Electron Devices Society Kolkata Chapter (EDKCON), pp. 12-17, doi: https://doi.org/10.1109/EDKCON56221.2022.10032936

[8] Kamalesh, M. S., Senthilnathan, N., Bharatiraja, C., Kumar, C., & Deepika, L. (2021). *Analysis of Ripples in SEPIC based Buck-Boost Converter for Low Power Applications.* Paper presented at the 2021 IEEE Madras Section Conference (MASCON), pp. 1-7, doi: https://doi.org/10.1109/MASCON51689.2021.9563360

[9] Hayder, W., Abid, A., Hamed, M. B., Ogliari, E., & Sbita, L. (2021). *Comparison of MPPT methods FLC & PSO for PV system under variable irradiance and temperature.* Paper presented at the 2021 18th International Multi-Conference on Systems, Signals & Devices (SSD), pp. 1247-1251, doi: https://doi.org/10.1109/SSD52085.2021.9429346

[10] Khairi, M. N. S., Bakhari, N. A. B., Samat, A. A. A., Kamarudin, N., Hussin, M. H. M., & Tajudin, A. I. (2023). *MPPT Design Using PSO Technique for Photovoltaic System.* Paper presented at the 2023 IEEE 3rd International Conference in Power Engineering Applications (ICPEA), pp. 131-136, doi: https://doi.org/10.1109/ICPEA56918.2023.10093161