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A New Topology of High-Efficiency DC-DC Hybrid Boost SEPIC Converter for PV Cell

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Abstract— This paper initiates a high-gain high efficiency step-up DC-DC converter based on Boost SEPIC (Single Ended Primary Inductor Converter) hybrid topology for photovoltaic application. Customarily DC-DC converter circuit is a widely used technique to improve the voltage level of solar cells. However, for low output voltage and low efficiency, they are not sufficient enough to provide expected outcomes. To defeat the conventional system a hybrid Boost SEPIC topology has been recommended with enhanced performance. The proposed design of the DC-DC converter circuit can provide a high voltage gain without decaying its overall performance. The modified converter topology is being worked by a single switch with low switching voltage stress over the semiconductor devices. The main edge of the proposed design is that it can perform efficiently without using any transformer, the combined design of Boost SEPIC topology increases the voltage gain much higher compared to the conventional Boost or SEPIC. The maximum Power Point Tracking (MPPT) algorithm is used to obtain maximum power from a photovoltaic source. MATLAB Simulink and PSIM software has analyzed the performance of the newly designed converter circuit thoroughly.

Keywords: *Step-up Converter, High voltage gain, SMPS, MOSFET Switch*

1. INTRODUCTION

In recent years, the fast ascent in power demand and the change in biological circumstances, for example, the rise of worldwide temperature by using traditional sources, for example, consumption of oil and coal brings about the developing greenhouse impact and contamination issues in the environment. It expands the need for novel assets of energy, which is modest and increasingly maintainable. Due to several reasons, the use of renewable energy is highly increased as clean and sustainable energy. From the available resources of renewable energy, solar energy is the biggest contributor to clean emission-free and inexpensive energy [1]. For the increasing demand for renewable energy systems, photovoltaic systems and semiconductors, the industry requires wide use of high-efficiency DC-DC power electronic converters. The output voltage levels from these sources are commonly low and unregulated and it doesn't coordinate with the load and should be expanded [2]. The most feasible and efficient way to increase the low voltage of a PV array and reduce the voltage strains on semiconductor components, according to several researchers, is to use high step-up DC-DC converters [3]. The easiest architectures for achieving a high-voltage gain are cascaded and multilayer converters, however because of the numerous stages and numerous power switches, they have low efficiency [4]. The output voltage of a PV cell usually ranges from 12 V to 50 V. Inherently DC-DC step-up converter is used for increasing the voltage level and output gain of solar energy [5]. Fig.1 Present a PV system where A DC-DC step-up converter is used to increase the output voltage of the PV source, which can be converted again to an AC output through an inverter to the load [6].

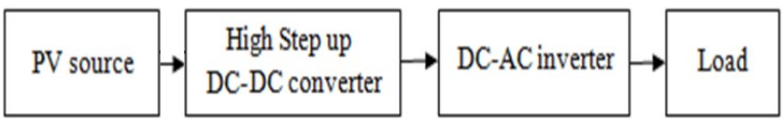

Fig. 1. Basic step-up of a photovoltaic system

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A high-frequency transformer can build the desired output however it has a certain disadvantage of leakage current due to the inductance of the transformer [7]. Nevertheless, to improve productivity, just as diminish the absolute leakage current, the converter without a transformer is examined throughout this research. Over the years, several solutions and topologies have been proposed by researchers for the improvement of the overall power quality of DC-DC converters, however, most of them suffer from low gain and low efficiency [2], [7]–[12]. The proposed topology introduces a hybrid DC-DC converter with a solitary switch. Topology consolidates two traditional DC-DC converters to improve the output gain without interfacing a mid-point transformer [13].

The conventional DC-DC converter experiences some power losses like losses in MOSFET, input & output capacitance loss, diode loss, inductor losses etc. The total power losses in a boost converter are the sum of all factors. In the case of SEPIC, similar difficulties are seen and the inductor and capacitor resistance affect the efficiency and output ripple [5]. DC-DC boost converter system is useful to increase the output voltage level. Due to the leakage resistance of the inductor, the performance of the conductor decreases with the increasing duty cycle ratio of the switch. Therefore, a traditional boost converter cannot be used for high voltage requirements [6]. The convergence of this paper is firstly to build up a DC-DC converter with a mix of boost and SEPIC together. It has significant merits such as high voltage gain and high efficiency which makes this design a good choice to be implemented. Additionally, the altered converter has been contrasted and different sorts of converters dependent on similar parameters and has been analyzed the performance of the adjusted boost SEPIC converter. The control of the proposed converter is simple because a single switch is utilized.

This paper is sectionalized into five sections. Section I of this article has described the background of conventional non-isolated DC-DC converters along with their limitation while connected with a photovoltaic system. The modelling and operation of the proposed circuit are described in section II. Section III is explaining the theoretical analysis of the ideal voltage gain of the proposed converter. Simulation result analyses have been broadly discussed in sections IV and V accordingly.

2. MODELLING OF MODIFIED BOOST-SEPIC CONVERTER

The proposed circuit that appeared in Fig. 2 is formed by the Boost converter and SEPIC converter. The major primacy of this converter is to lessen the number of switches and inductors contrasted with the other existing isolated converters. For the most part, the voltage stress over the switch is in addition diminished alongside the decrease in input current ripple. The boost converter has the advantage of high step-up voltage gain whereas the SEPIC converter has the merits of continuous input and output current. The proper combination of both topologies can enhance the overall performance of the desired parameter which can contribute to optimizing the performance of solar PV cells.

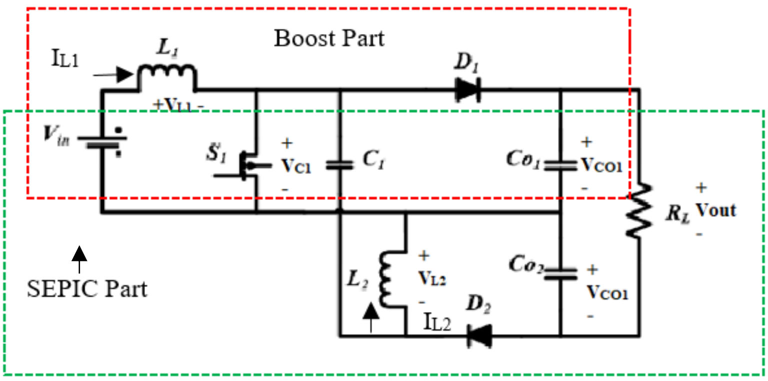

Fig. 2. Proposed DC-DC hybrid boost SEPIC converter

The principle of operation of the proposed hybrid circuit has been explained in Fig. 3 and 4 respectively. The circuit has used five passive elements and two diodes. A MOSFET is used as a switch. The circuit operation can be classified into two types based on the ON and OFF operation of the MOSFET switch. When the switch of S_1 is turned on, the diode D_1 does not direct for being reversely biased, in this way, consequently current in inductor L_1 will build up, thus capacitor C_{O1} and C_{O2} will be charged equally. The direction of current flow during switch ON mode is shown in Fig. 3.

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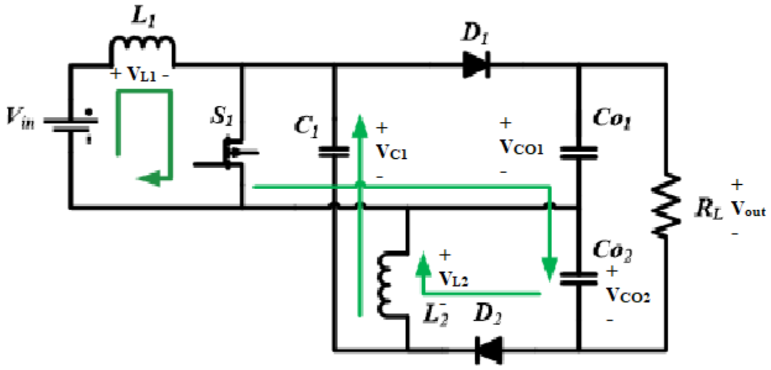

Fig. 3. Mode 1, currents in the circuit during switch ON

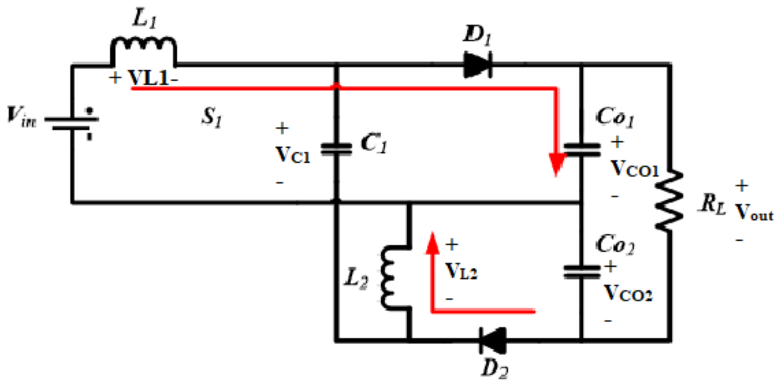

Fig. 4. Mode 2, currents in the circuit during switch OFF

When the MOSFET Switch S_1 is off; the Diode D_1 has led for its forward one-sided Voltage. An inductor will release its stored energy and the current will continue to flow as shown in Fig. 4. The simulation setup of the proposed circuit is depicted in Fig. 5 (a). Perturb and observe-based MPPT algorithm is used to obtain maximum power from the solar module. Fig. 5 (b) shows the block of MPPT to generate the desired duty cycle for pulse width modulation (PWM) of the MOSFET switch. Perturb and the observe-based algorithm is shown in Fig. 5 (c). The theoretical waveform of inductor current L_1 and L_2 during switch ON and OFF conditions is demonstrated in Fig. 6.

3. ANALYSIS OF PROPOSED HYBRID CONVERTER

In order to determine the voltage, and gain equation of the proposed converter all semiconductor components, capacitors and inductors are assumed to be ideal. The circuit is operating in continuous conduction mode at a steady state.

The voltage gain of the proposed hybrid converter circuit is calculated using the assumption that the inductors' steady-state average voltages V_{L1} and V_{L2} over one switching cycle is zero. applying Kirchhoff's voltage law, the voltage drop across the inductor from Fig. 3 and Fig. 4 for both modes of operation is given in Eq. (1) and Eq. (3) respectively.

$$\int_0^{T_s} V_{L1}(t)dt = D_{Ts}V_{in} + [(1-D)T_s](V_{in} - V_{CO1}) \quad (1)$$

Where D is the duty cycle ratio of the MOSFET switch and T_s is the switching period. The duty cycle can be calculated using the following equation.

$$D = \frac{T_{ON}}{T_s} \quad (2)$$

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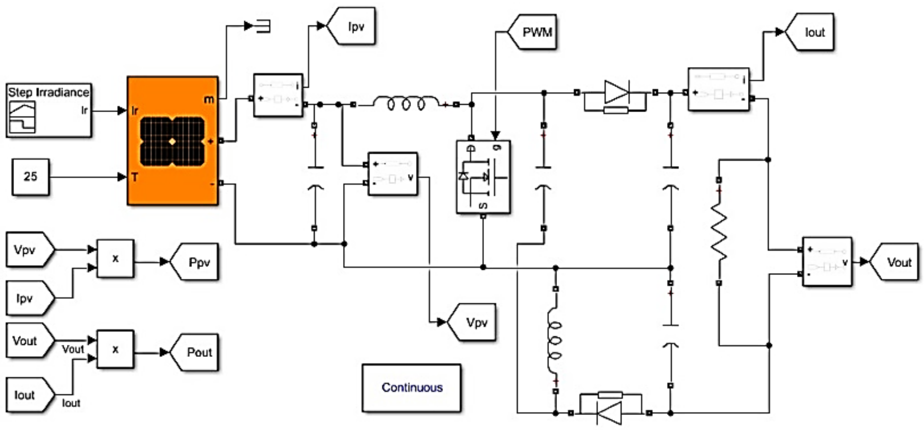
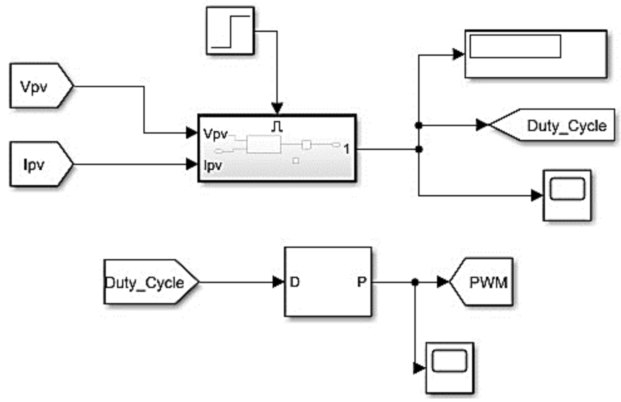


(a)



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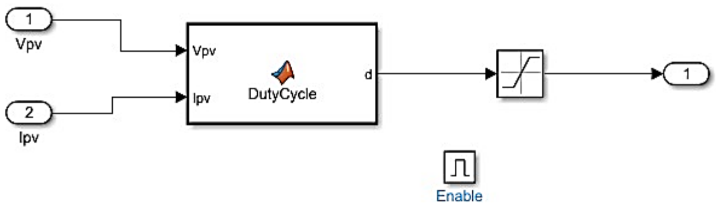


(c)

Fig. 5. (a) Simulation setup in Simulink, (b) Block diagram of MPPT controller (c) Perturb and observe algorithm block

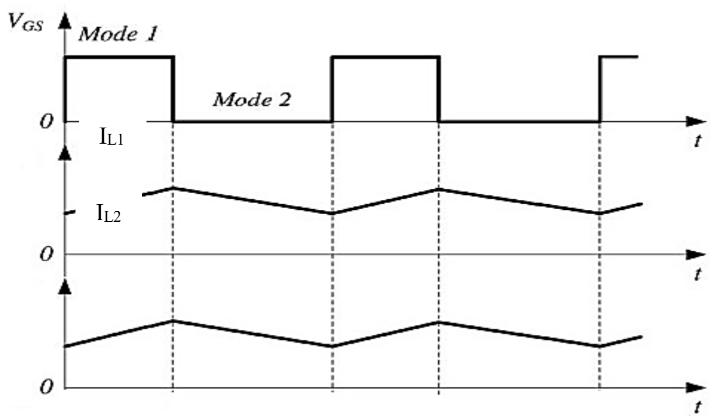


Fig. 6. Voltage and current waveform in different modes

Since voltage in the second balance, over one switching cycle is zero. The voltage across capacitor C1 can be calculated using Eq. 1.

$$V_{CO1} = \frac{V_{in}}{1-D} \tag{3}$$

Apply volt second balance theorem on L_2 over one switching cycle we will get

$$\int_0^{T_s} V_{L2}(t)dt = D_{Ts}(V_{in} - V_{CO2}) + (1-D)T_s V_{CO2} \tag{4}$$

Solving Eq. 4, voltage across capacitor C2 can be written as,

$$V_{CO2} = \left(\frac{D}{1-2D}\right) V_{in} \tag{5}$$

The net output voltage of the circuit can be calculated as,

$$V_{out} = V_{CO1} + V_{CO2} \tag{6}$$

Putting Eq. 4 and Eq. 5 in Eq. 6 to calculate the voltage gain

$$G_V = \frac{V_{out}}{V_{in}} = \frac{(1-D)^2 + D}{(1-D)(1-2D)} \tag{7}$$

4. RESULT

The chosen value of the proposed circuit along with its performance is given in detail in this section. The analysis and simulation have progressed by using PSIM and Simulink software. Table I contains the values of the component which have been selected for simulation. Table II reveals the outstanding performance in terms of output voltage and efficiency of the proposed design compared to conventional design. During simulation, conventional converters and the hybrid Boost-SEPIC converter operate at the same input voltage (36V) and same switching frequency (20kHz) and same value parameter.

TABLE 1: SPECIFICATION OF CIRCUIT PARAMETERS

Parameter	Value
CAPACITOR (C_1)	470 UF
CAPACITOR ($CO_1 = CO_2$)	470 UF
INDUCTOR ($L_1 = L_2$)	4.7 MH
LOAD RESISTOR (R)	50 Ω
SWITCHING FREQUENCY (F)	20 KHZ
SOLAR IRRADIANCE	1000W/M^2
TEMPERATURE	25^o
PHOTOVOLTAIC OUTPUT VOLTAGE	36V

TABLE II: EFFICIENCY AND OUTPUT VOLTAGE COMPARISON

Converters	Boost	SEPIC	Boost-SEPIC
EFFICIENCY	94.83%	87.64 %	98.60%
OUTPUT VOLTAGE	74V	38V	126 V

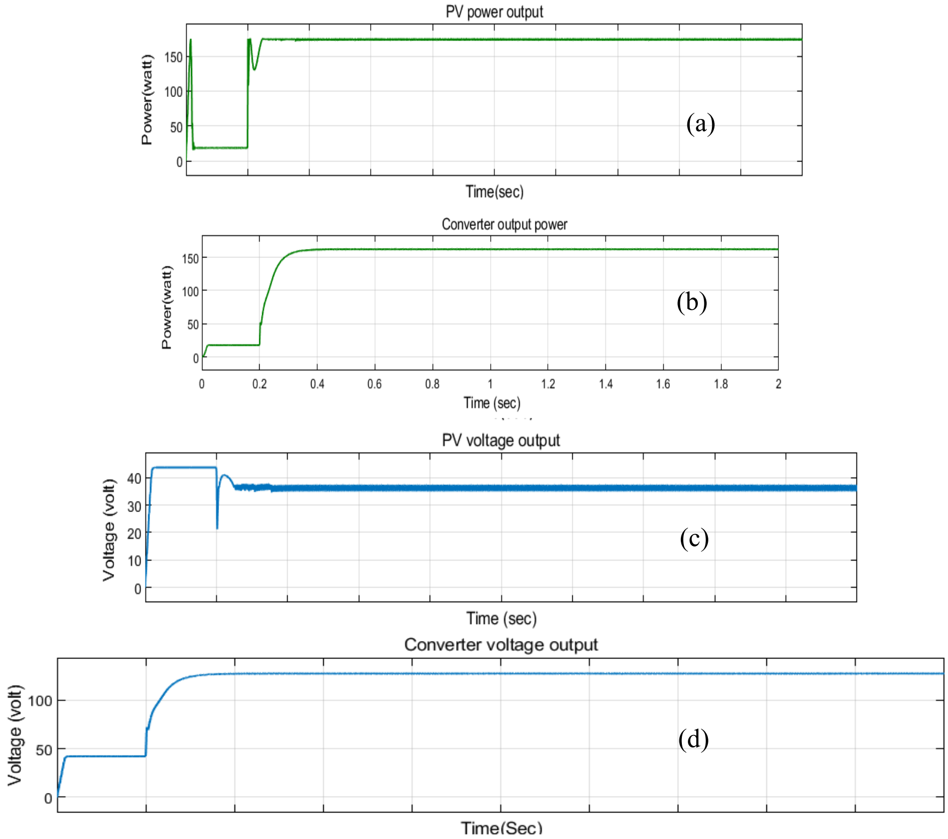


Fig. 7. Waveform of (a) PV Power output, (b) Converter power output, (c) PV voltage output and (d) Converter voltage output

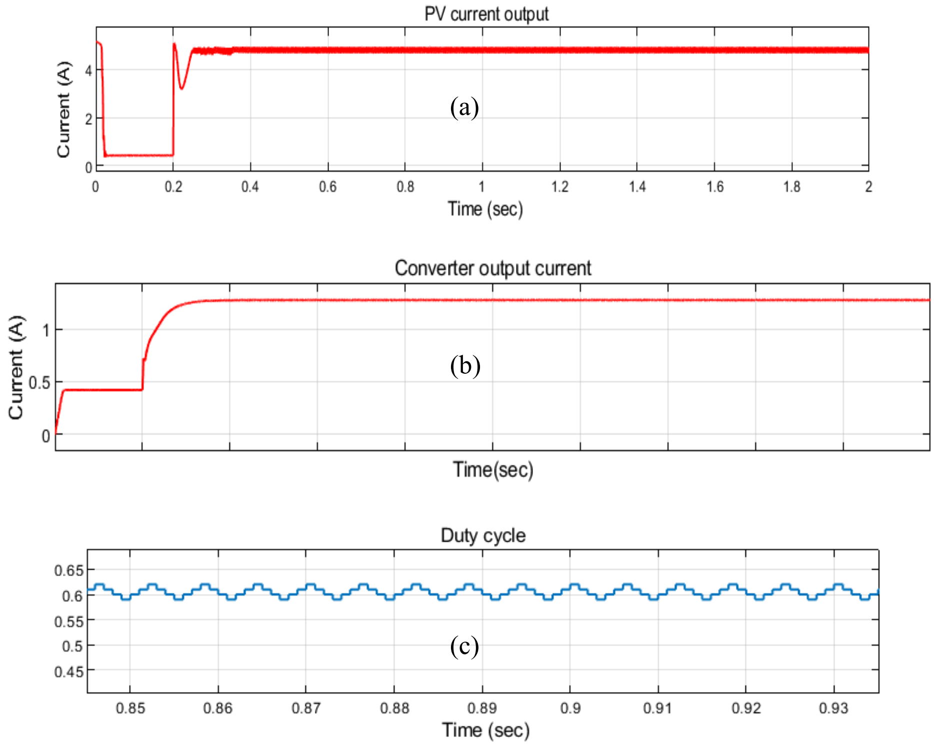
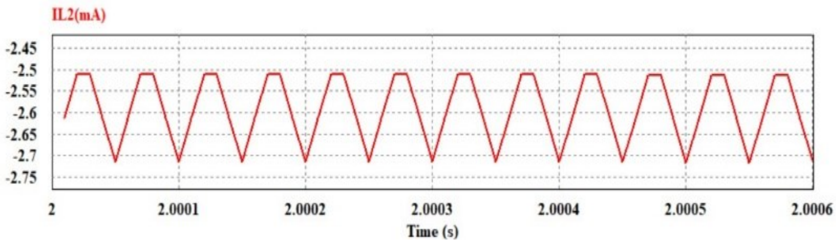


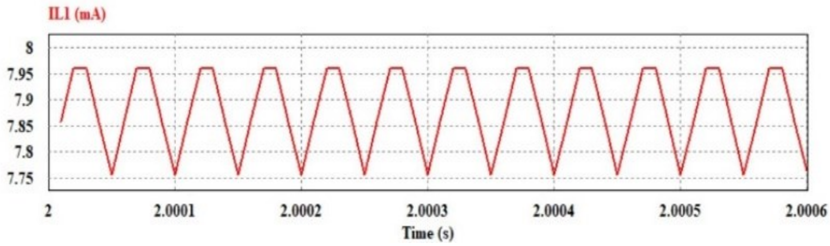
Fig. 8. Waveform, (a) PV current output, (b) Converter current output and (c) Duty cycle

TABLE 2: OUTPUT PERFORMANCE COMPARISON

CONVERTERS	BOOST	SEPIC	BOOST-SEPIC
EFFICIENCY	94.83%	87.64 %	98.60%
OUTPUT VOLTAGE	74V	38V	126 V

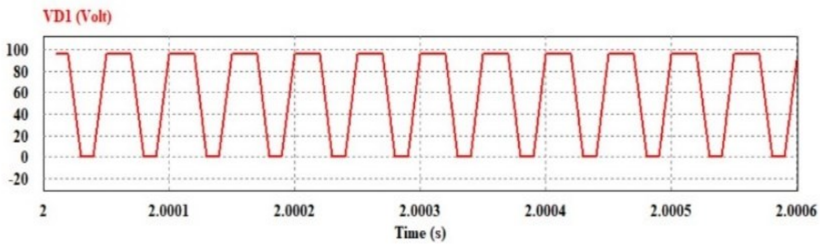


(a)

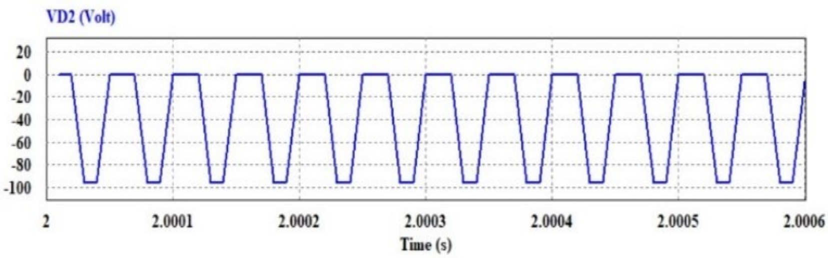


(b)

Fig. 9. Current waveform (a) Inductor L_1 and (b) Inductor L_2



(a)



(b)

Fig. 10. Voltage waveform across diode, (a) D_1 and (b) D_2

5. RESULT ANALYSIS

Simulation results of conventional and proposed circuits are shown graphically in this section. Fig. 7 displays the waveform of PV and converter power and voltage output. It is understandable from the figures. that proposed hybrid model is performing significantly better. From Fig. 8(c) and Fig. 8(d) it is visible that the proposed circuit noticeably reduced the fluctuation of output voltage compared to input. Similarly, the converter output current also contains less ripple, which is shown in Fig. 9(b). Current flowing through inductors L1 and L2 in Fig. 10 has the same waveform at CCM similar to the theoretical waveform. Fig. 11 displays the efficiency of the conventional converter and proposed converter in the same parametric situation. It is visible from the graphical representation that the proposed circuit outperforms compared to other converter circuits in all possible manners throughout the variation of the duty cycle, which is depicted in Fig. 11.

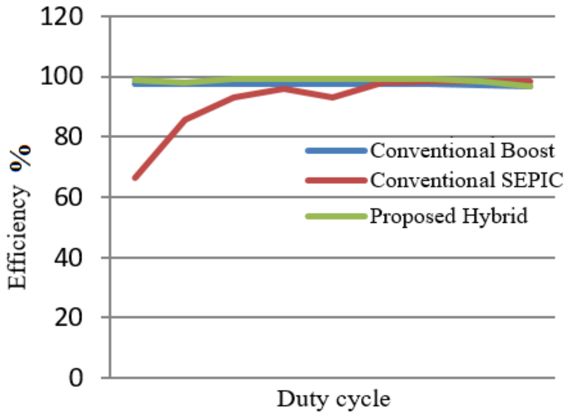


Fig. 11. Efficiency comparison of various converter

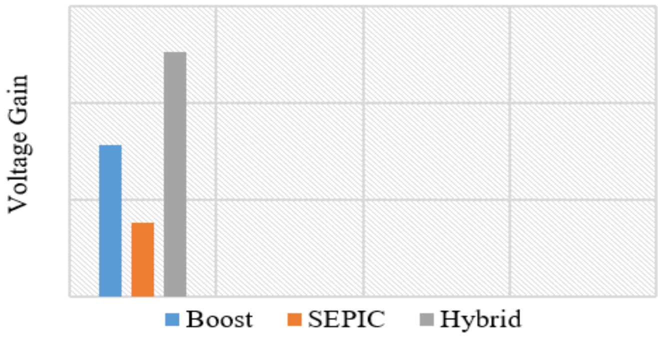


Fig. 12. Voltage gain of the conventional and proposed converter

Fig. 12 is indicating the voltage gain of the proposed converter is the highest among all other converter circuits. The proposed converter can perform efficiently for different values of loads and switching frequency, which have been shown in Fig. 14 and 15 respectively.

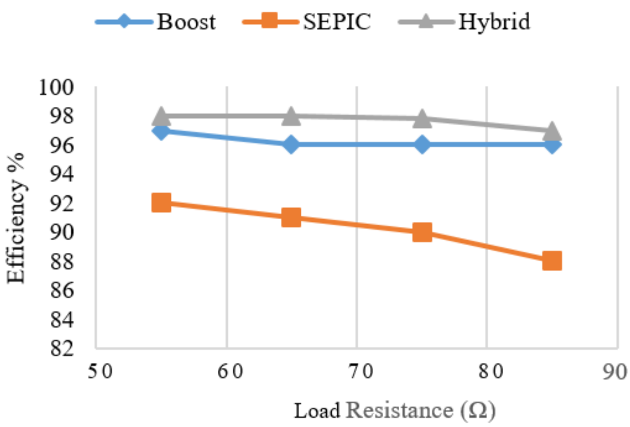


Fig. 13. Observation of efficiency under load variation

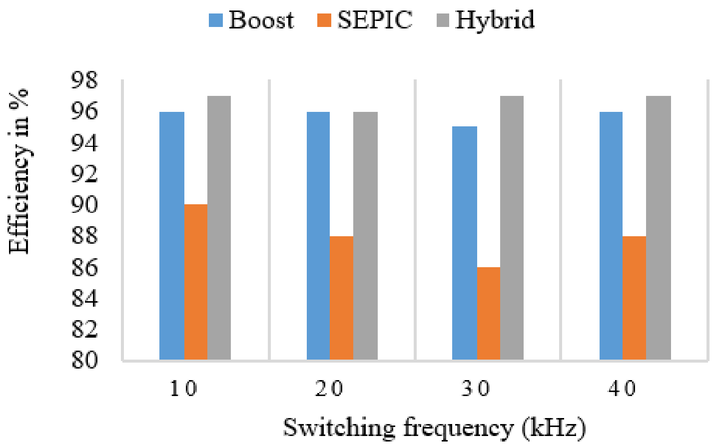


Fig. 14. Observation of efficiency under frequency variation

6. Conclusion

The analysis of the proposed hybrid Boost- SEPIC DC-DC converter depending on SMPS technology is carried out to boost the output voltage level of the photovoltaic cell. Surveying of the proposed design shows that the high voltage gains and continuous current conversion is possible to achieve without worsening the transformation efficiency. Besides that, the proposed circuit is also able to eliminate the switching and other circuit element stress. The performance of the converter has been simulated and tested under different parameters variation such as switching frequencies, duty cycle and load with the help of PSIM and Simulink software. From the result analysis, it is obvious that the recommended configuration is performing better than the existing configuration. The proposed converter demonstrated its capacity to meet solar source requirements by offering a high amplitude and efficiency of 98%.

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