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A Rectifier-fed DC-DC Boost Converter with Improved Voltage Conversion Ratio and Reduced Output Voltage Ripple

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Abstract: In this paper, the simulation analysis of a non-isolated diode rectifier-fed DC-DC boost converter with high voltage gain is presented. The proposed two-switch converter is operated in continuous conduction mode (CCM). The suggested converter exhibits improved voltage gain compared to the traditional boost converter and other topologies. The simulation of the proposed two-switch converter with switching frequency of 50 kHz has been carried out in MATLAB/SIMULINK environment. An uncontrolled diode bridge rectifier supplies the rectified DC voltage to the proposed DC-DC converter. The AC input supply to the rectifier is 25 V (rms). This voltage is converted into around 24 V (DC) at the output of the rectifier stage. At the output of the DC-DC converter, a DC voltage of 370 V is obtained for the same duty cycle (k) of 70% for the two switches. The converter is capable to provide wide range of high step-up output voltage with significantly reduced overshoot and settling time for a range of duty cycle (k). However, the converter can produce high value of output voltage at low duty cycle itself. The ripple content in the output voltage is very much reduced with the help of a suitable filter capacitor at the output. Further, low voltage stress is observed on the two active switches.

Keywords: CCM, Duty cycle, MATLAB/SIMULINK, Ripple content, Two-switch DC-DC converter topology, Voltage gain.

I. INTRODUCTION

The recent research focus is towards the improvement of the voltage gain of DC-DC converters appropriate for renewable energy applications. Despite the robust environmental and financial effects of renewable energy sources like photovoltaic (PV) and wind energy conversion, they have low output voltage, and there are some limitations on their use [1]. High-step-up DC-DC converters have been used to get rid of the restriction [1]. There are two categories of DC-DC conversion configurations such as non-isolated and isolated structures. The isolated structures can achieve high voltage conversion ratio. However, there are certain drawbacks associated with them [2]-[3]. The transformerless configurations with high voltage gain and simple control strategy are preferred for most of the applications.

In recent times, as per the demands of modern applications, certain highly efficient and reduced switch count structures have been developed with low switch voltage stress for non-isolated high gain DC-DC converters [4]. Some authors summarized the review of certain high step-up non-isolated DC-DC converters [5]-[7]. There are certain voltage boosting techniques such as switched capacitor, voltage multiplier, switched inductor, magnetic coupling, and multi-level concept. Depending on the application, each of the above techniques has their own merits and demerits in terms of price, complexity, power density, and reliability. With the proper duty cycle and low turns ratio, the coupled inductor method in combination with the super-lift technique can produce a greater voltage gain with reduced voltage stress on the active switches [8]-[9]. The Voltage Multiplier Cells (VMCs), comprised of switched inductors and switched capacitors, are employed in DC-DC converters to achieve high voltage gain [10]. The proposed single switch topology proposed in [9] has the benefits of reduced switch voltage stress and high voltage gain.

There is a need for improving the DC voltage profile in DC microgrid applications. The high step-up gain DC-DC converters play a significant role in DC microgrid for voltage gain improvement [11]. With the available AC supply, the DC-DC converters can be energized from AC source through rectifier. The topology of an AC-DC converter with single switch capable of producing wide range of voltage gain is proposed for SMPS applications in [12]-[13].

The traditional DC-DC boost converter can have high voltage gain at high duty ratio [14]-[15]. The high duty ratio of the conventional DC-DC boost converters is responsible for the reduction in efficiency of the conversion scheme. The high

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voltage gain can be achieved by connecting the converters in series. But, it leads to increased cost of conversion. Certain non-isolated positive output converters like SEPIC (Single Ended Primary Inductor Converter) and the CUK converter providing inverting output have simple control, reduced complexity, and cost effective. However, the SEPIC structure has drawbacks of poor voltage gain and complex duty cycle control for multiple output systems energized by multiple inputs.

The drawback of CUK converter is that the proper converter operation requires complex compensation circuitry.

This paper suggests a high step-up non-isolated DC-DC converter with high voltage conversion ratio and reduced ripples in the output voltage. The proposed converter is fed by a diode bridge rectifier. The ripples in the output of the rectifier are filtered out by a suitable choice of capacitor. The converter has two active switches and less number of passive components. The same duty cycle is used for the control of two active switches. Due to the use of two inductors in the converter, the voltage gain is improved. At low duty cycle itself, the converter produces high DC output voltage [16]. The ripples present in the output voltage of the converter proposed in [15] are further reduced by introducing a suitable capacitor at the output. The low voltage stress is observed on the two power switches and the diodes in the converter.

The remaining part of the paper is organized as follows: Section II elaborates on the proposed rectifier-fed DC-DC converter topology and its modes of operation. The simulation results and discussion for the proposed high gain DC-DC converter are presented in Section III. The features of the proposed work are given in Section IV.

II. PROPOSED NON-ISOLATED DC-DC CONVERTER TOPOLOGY WITH IMPROVED VOLTAGE GAIN

The proposed non-isolated DC-DC converter with improved voltage gain is fed by a diode bridge rectifier as shown in Fig. 1. The converter is operated in continuous inductor current mode. The converter has two active switches S_1 and S_2 with same duty cycle, two identical inductors L_1 and L_2, four capacitors C_1, C_2, C_3, and C_4, and three main diodes D_1, D_2, and D_3 respectively. The capacitor C_4 acts as filter capacitor for filtering out the ripples present in the DC output voltage of the converter.

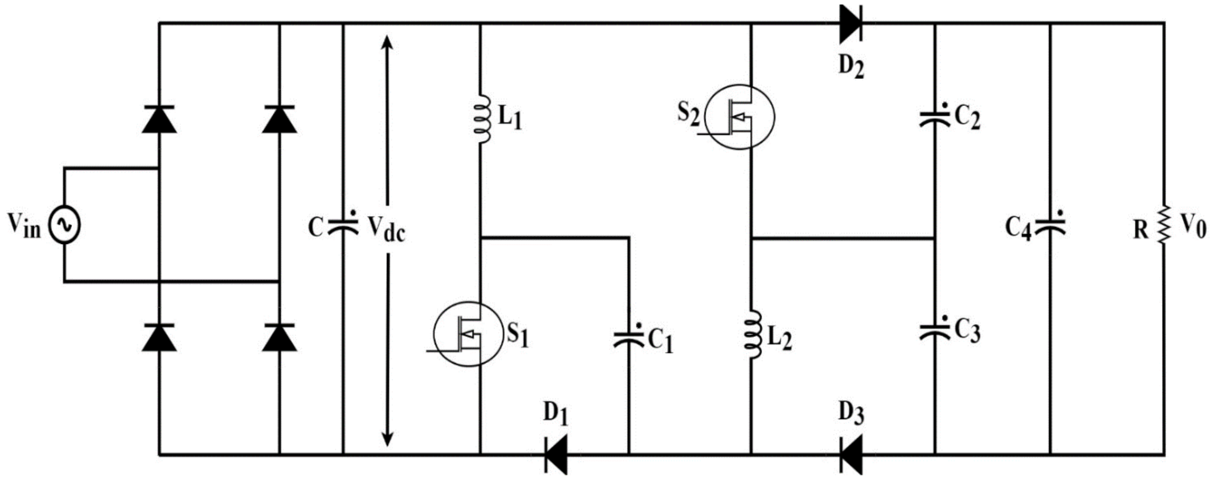

Fig. 1. Power circuit diagram of the proposed non-isolated DC-DC converter with improved voltage gain

The proposed converter topology has two modes of operation. During mode-I operation, both switches S_1 and S_2 are turned ON, the inductor L_1 is magnetized by the input voltage (V_{dc}) and the capacitor (C_1) is charged. The diodes D_1 and D_2 are reverse biased, and D_3 is forward biased. The inductor L_2 is magnetized by the summation of the voltage across the capacitor (C_1) and the input voltage (V_{dc}). The filter capacitor C_4 supplies the load current. The equivalent circuit of the converter for mode-I is shown in Fig. 2. The inductor voltages are given by Equation (1).

$$V_{L1} = V_{dc}\,; \qquad V_{L2} = V_{dc} + V_{C1} \qquad (1)$$

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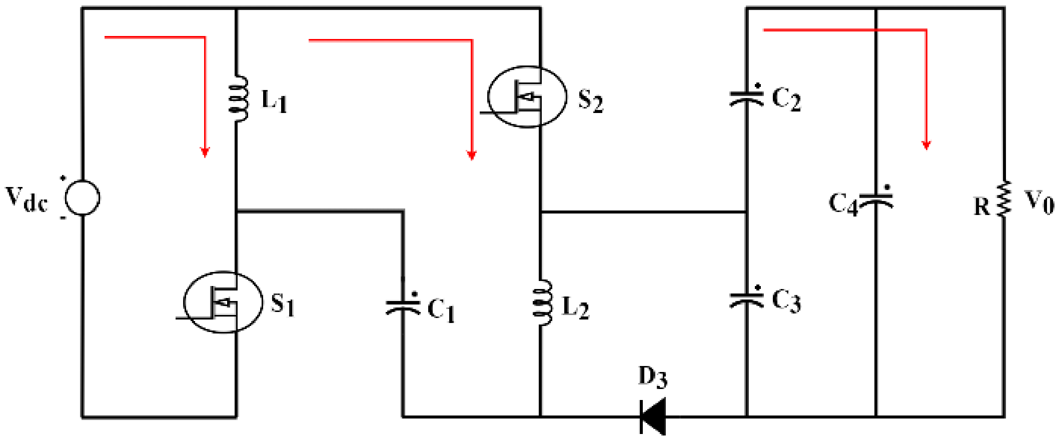

Fig. 2. Equivalent circuit of the converter during Mode-I

During mode-II operation, both switches S_1 and S_2 are turned OFF, and the inductor L_1 is demagnetized through the capacitor C_1 and the diode D_1. The diodes D_1 and D_2 are forward biased, and the diode D_3 gets reverse biased. The inductor L_2 discharges its energy through the diode D_1 and the voltage across the capacitor C_2 is equal to that of capacitor C_4. The corresponding equivalent circuit is shown in Fig. 3. The inductor voltages are given by Equation (2).

$$V_{L1} = V_{dc} - V_{C1}\,; \qquad V_{L2} = V_{dc} - V_0 \tag{2}$$

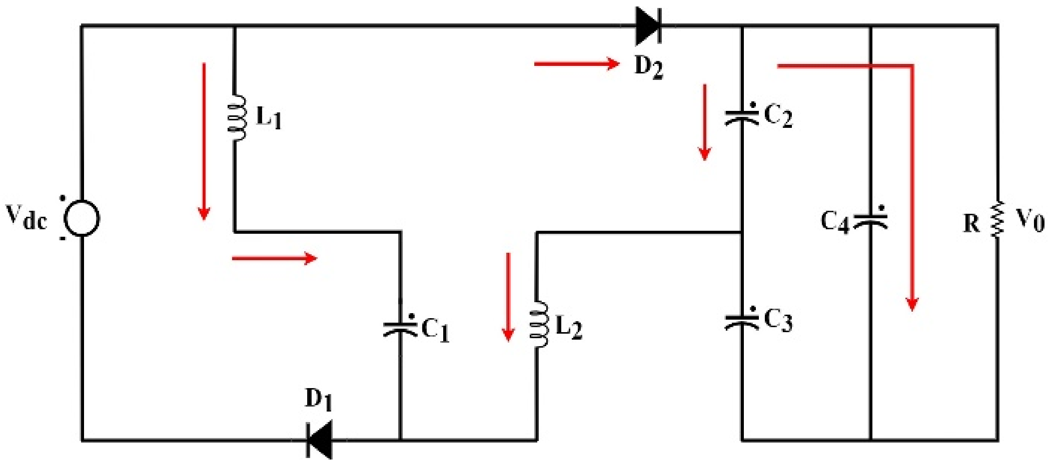

Fig. 3. Equivalent circuit of the converter during Mode-II

The volt-second balance principle is applied to the two inductors L_1 and L_2 during mode-I and mode-II and the following equations (3) and (4) are obtained.

$$V_{dc}k + (V_{dc} - V_{C1})(1-k) = 0 \tag{3}$$

$$(V_{dc} + V_{C1})k + (V_{dc} - V_0)(1-k) = 0 \tag{4}$$

From the above equations, the voltage gain equation (G_{CCM}) of the proposed converter with duty ratio 'k' is derived as shown by the Equation (5).

$$G_{CCM} = \frac{V_0}{V_{dc}} = \frac{k^2 - 3k - 3}{(1-k)^2} \tag{5}$$

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III. SIMULATION RESULTS AND DISCUSSION

The proposed rectifier-fed non-isolated DC-DC converter is simulated using the MATLAB/SIMULINK software as shown in Fig. 4. The continuous inductor current mode operation of the converter is considered. The switching frequency (f_s) of the converter is chosen as 50 kHz. The simulation model is developed using the Simulink library and the 'ode23tb' solver. The MOSFET switches and the diodes are assumed to be ideal.

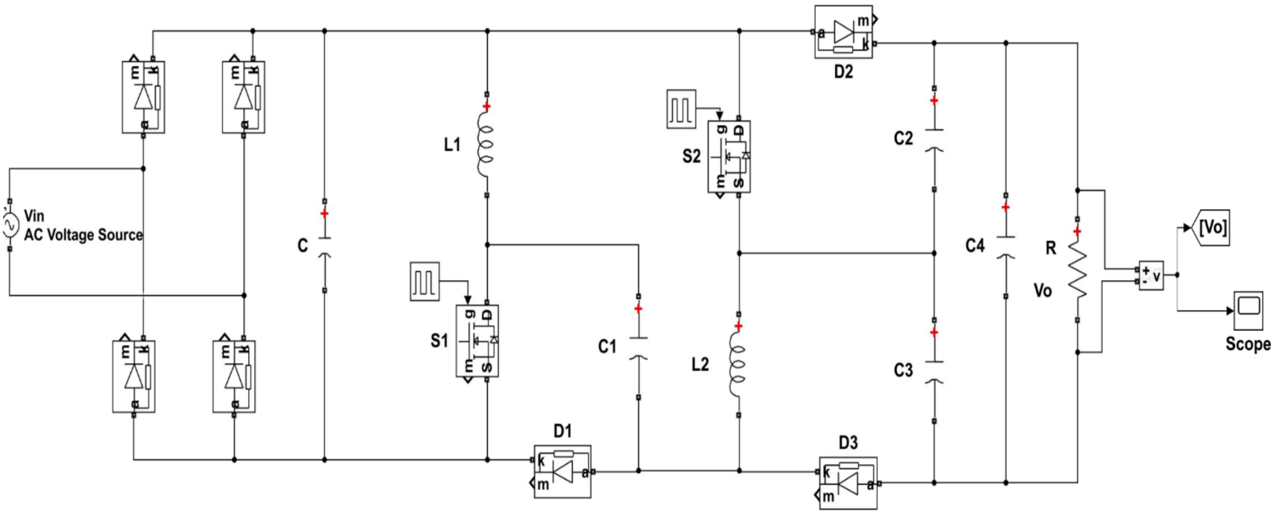

Fig. 4. Simulink model of the proposed converter

Based on the design considerations, the values of passive components are obtained. The simulation parameters and the specifications of the converter are listed in Table I and II. The power graphical user interface (power GUI) is used for solving process simulations with a stop time of 5 sec. The duty ratio (k) is chosen as 0.7 for both switches S_1 and S_2. The PWM gating pulses to the MOSFET switches S_1 and S_2 are shown in Fig. 5. The simulation results of the proposed converter are shown in Fig. 6, Fig. 7, Fig. 8, Fig. 9, Fig. 10, Fig. 11, Fig. 12, and Fig. 13 respectively. The simulation results demonstrate that the proposed converter has improved output voltage with lower amount of ripples.

TABLE I: SIMULATION PARAMETERS FOR THE PROPOSED CONVERTER TOPOLOGY

Circuit components	Values
Inductors (L_1, L_2)	0.5 mH
Filter Capacitor (C)	100 µF
Capacitors (C_1, C_2, C_3, C_4)	1000 µF each
Load Resistance (R)	290 Ω
Duty ratio (k) of the Switch S_1 & S_2	0.7

TABLE III: SPECIFICATIONS OF THE PROPOSED CONVERTER TOPOLOGY

Specifications	Values
Input AC voltage (V_i)	$(35/\sqrt{2})$ V (rms)
Output voltage (V_0)	371 V (DC)
Switching frequency (f_s)	50 kHz
Maximum output power (P_0)	474 W
Average output current (I_0)	1.28 A

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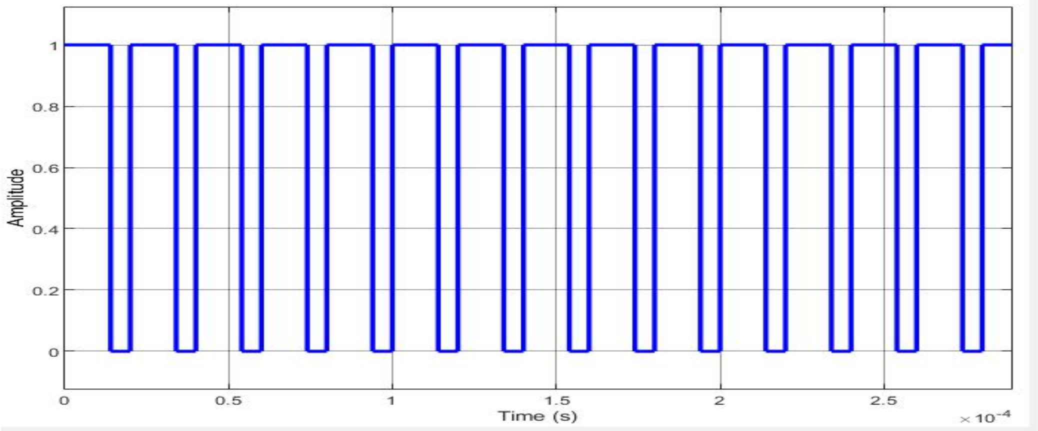

Fig. 5. PWM pulse waveform for the switches S_1 and S_2

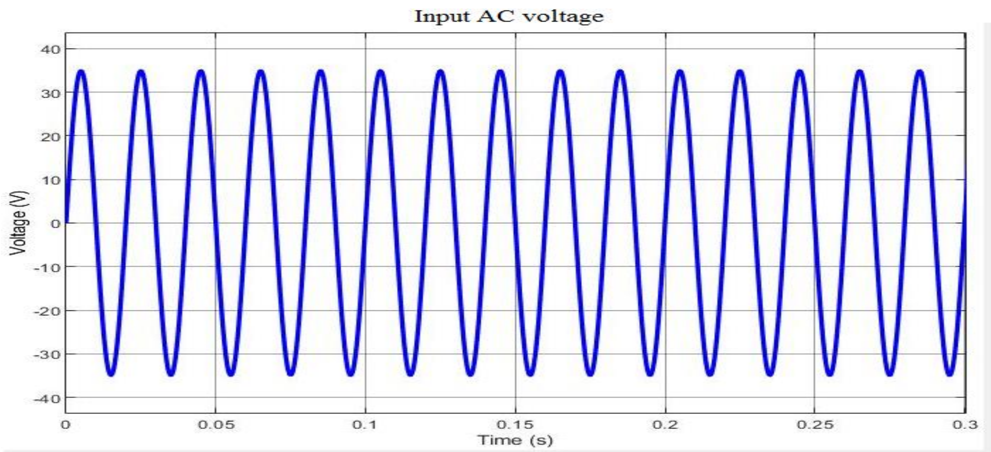

Fig. 6. Input AC voltage waveform

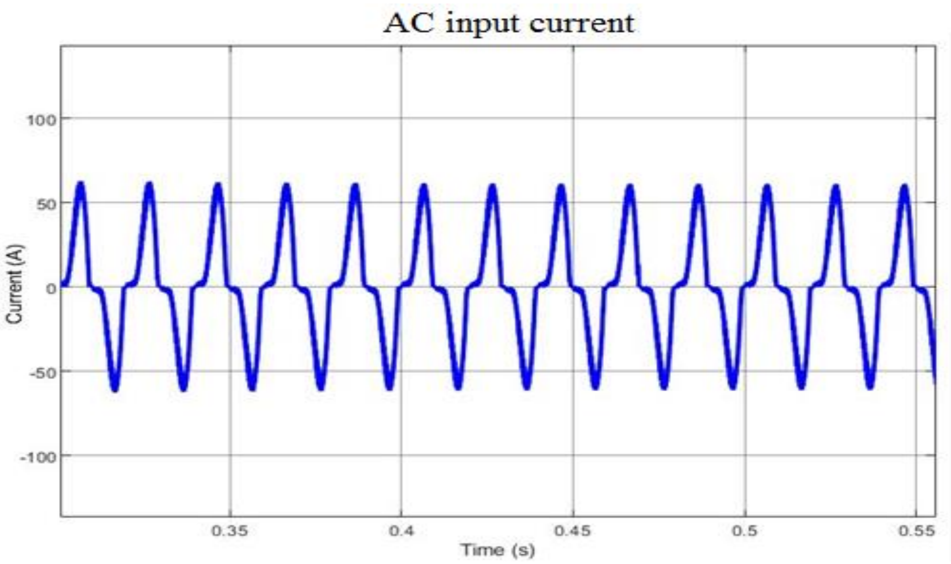

Fig. 7. Input AC current waveform

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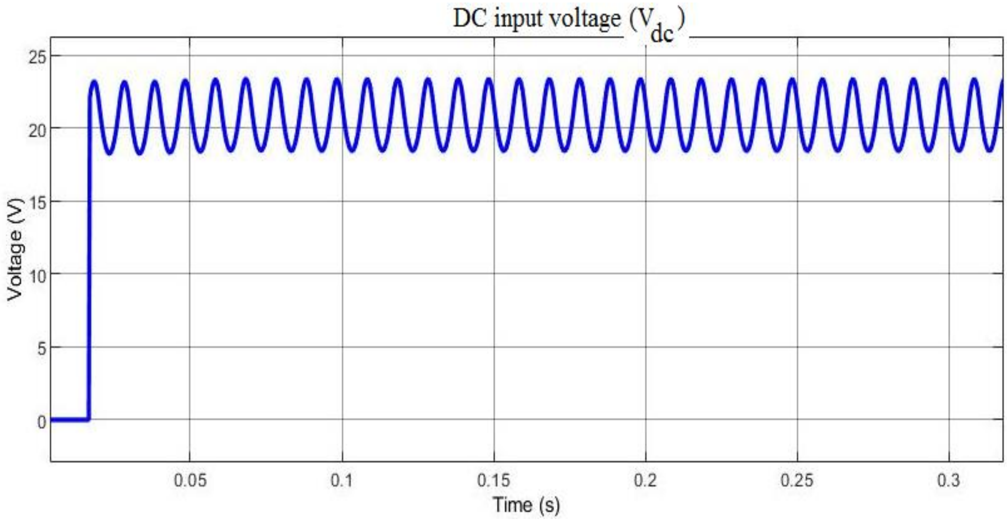

Fig. 8. DC input voltage (V_{dc})

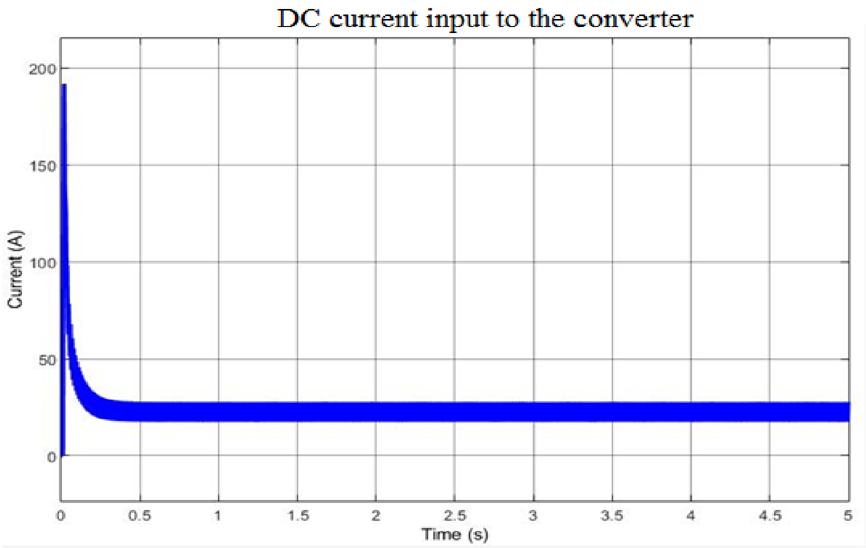

Fig. 9. DC input current (I_{dc})

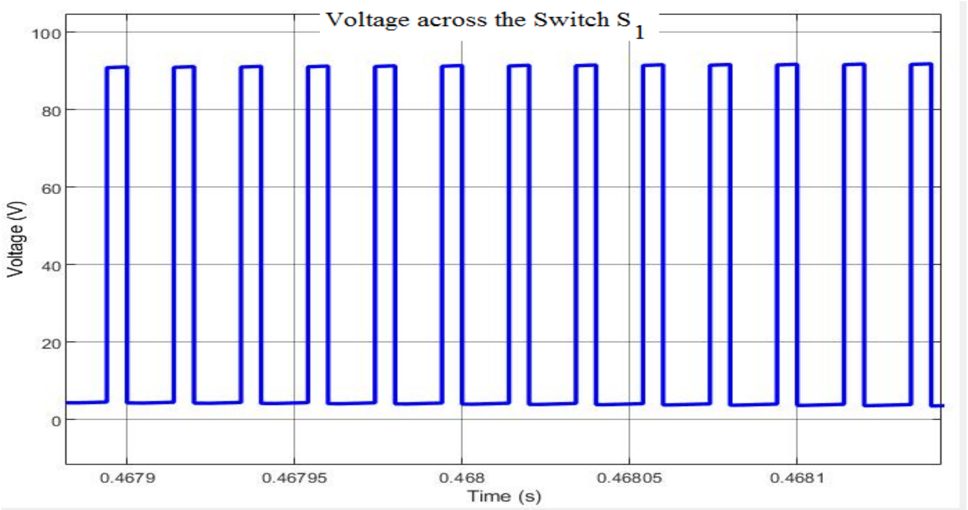

Fig. 10. Voltage stress across the Switch S_1

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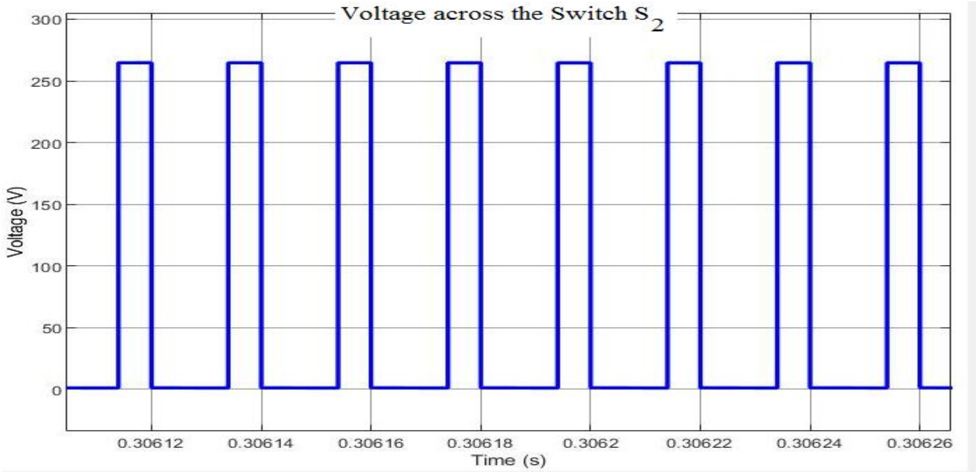

Fig. 11. Voltage stress across the Switch S_2

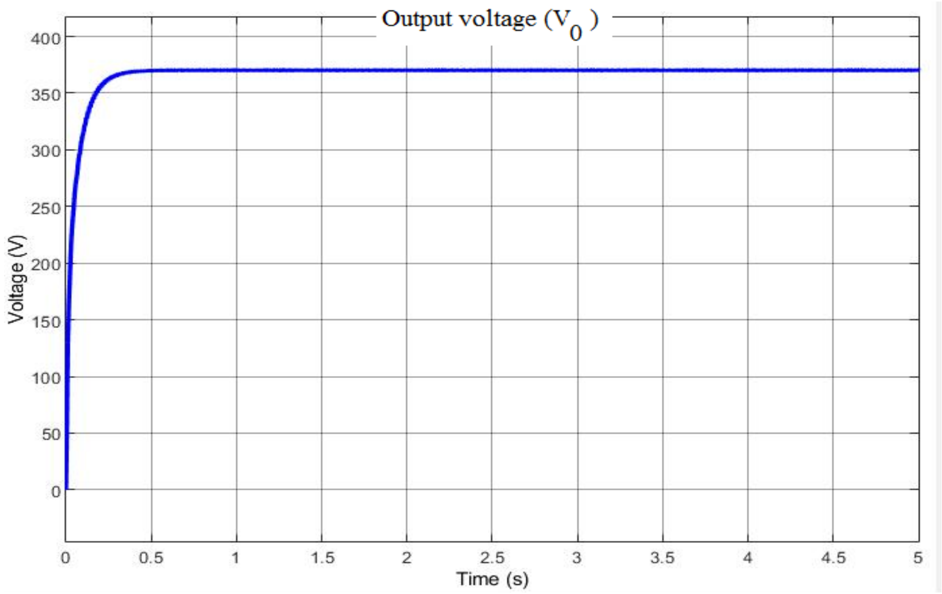

Fig. 12. Load voltage (V_0)

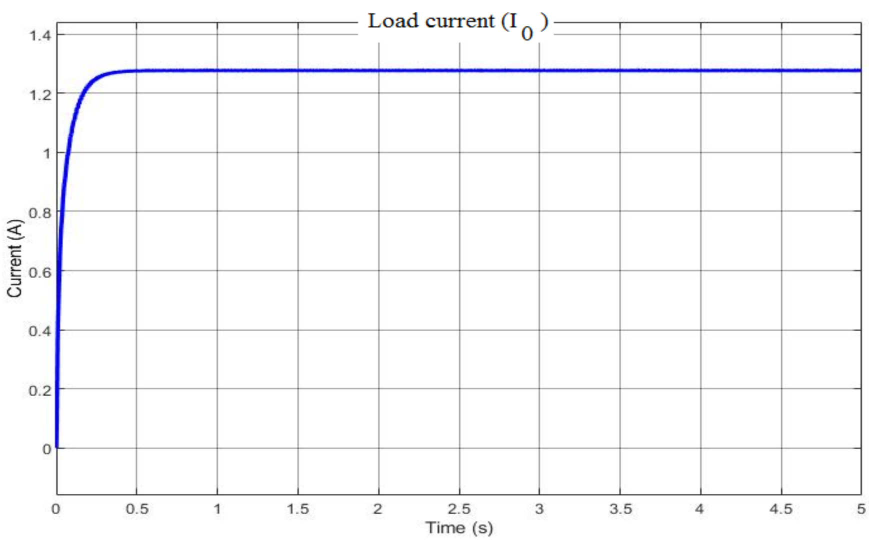

Fig. 13. Load current (I_0)

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IV. CONCLUSION

This paper presents the simulation analysis of a rectifier-fed high gain DC-DC converter operated in continuous inductor current mode. The AC input voltage is 35V (max). The AC supply frequency is taken as 50 Hz. The converter has been simulated in MATLAB / SIMULINK environment. The switches are triggered using Pulse Width Modulation (PWM) pulses produced by pulse generator. The duty ratio (k) of 0.7 is used for both active switches. The results demonstrate that the proposed converter is capable of producing output voltage (V_0) of 371 V which is 15.44 times the average input DC voltage (V_{dc}) of 24 V. The proposed converter exhibits improved voltage gain at low duty cycle itself. The switching losses and the voltage stress across the switches are found to be low. The ripple content in the DC output voltage is found to be less than 5% due to the proper selection of filter capacitor C_4. The suggested converter may find applications in electric vehicle and renewable energy based power generation.

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