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A New High Gain DC-DC Boost Converter with Continuous Input and Output Currents

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Abstract **–The fundamental DC-DC boost converter has the drawbacks of low voltage gain ratio followed by discontinuous output current. May the reverse recovery problem rises as a disaster for the output diode along with harming the power switch. Also the stress of voltage is significantly high in respect with the output voltage. Therefore, a new topology of high gain non-isolated DC-DC boost converter is proposed in this paper. In this converter a high voltage gain is achieved with continuous power in the input and the output. The voltage stresses across the semiconductors are all less than that of fundamental boost converter in respect with the output voltage. Only a single power switch is controlled by PWM which leads to simplicity and cost reduction. The proposed converter is advisable for PV panels because of its continuous input current. Furthermore, as the output current is also continuous this makes it a suitable choice for fuel cells. Simulations are provided in MATLAB Simulink to verify the extracted theoretical equations from the proposed converter.**

Index Terms – DC-DC boost converter, non-isolated, high gain, continuous input and output power.

I. INTRODUCTION

Due to significant inflation in air pollution, reduction of fossil fuel reserves and their high prices, many countries are forced to utilize the alternative sources such as: fuel cells (FC), Photovoltaic (PV) and wind turbines. Most of these sources have dc voltages on their outputs which are usually low [2-4]. For instance, to achieve a higher voltage level for PV panels, series connection of sources can be used whichever have their own advantages and drawbacks. If multiple solar modules stand in series connection and all of them do not receive uniform irradiation, the extracted power decreases in compare with the accessible power. Furthermore, tracking the global maximum power point in this condition is another challenge that may rise in this situation [5]. The aforementioned problem can be solved by utilizing the separated DC-DC boost converters. Generally, the main purpose of applying a boost converter is to control these sources independently and also transmitting energy from these sources along with delivering to the power grid at higher voltage levels [6]. Nevertheless, the fundamental boost converter can encounter some drawbacks. For example, the high voltages can be attained by increasing the duty cycle. However, due to the reasons such as saturation, reverse recovery problem and low efficiency, the conversion ratio can not be greatly increased practical ly. On the other hand, the power switch experiences the voltage stress as the same as the output diode connected to the load which is relatively large and requires a high priced power switch in the circuit. Another concern in boost converters is the need for continuous power in the input and the output. However, the output power in a fundamental DC-DC boost converter is discontinuous (pulsating). This shortcoming causes significant ripples at the output and put the output diode in danger of reverse recovery problem [7-10]. The importance of having continuous currents becomes greater where the absorbed power of PV panels depends on the input DC power of the connected converter. Hence, if the input current is discontinuous, the amount of output energy decreases based on PV current and power characteristic. Moreover, the requirement of continuous output current becomes important where some sources such as fuel cells need a uniform output current in order to adjust their output power. In order to build a continuous for both ports, a power converter should be designed with inductors in the input and the output of the structure [11].

Over and above that, a proper DC-DC boost converter should have some beneficial features acting as: high voltage gain ratio, low power losses, low number of elements, fewer stress across the power switch and diodes, lower volume and weight, and also having continuous input and output current [12-14]. This paper is up for a novel DC-DC boost converter. In this topology the input power can be transferred to the output at significantly high voltage gain ratio without utilizing any transformers or coupled inductors, as well as switched capacitors/inductors. Only a single power switch is used with low voltage stress on which makes this converter easy to be controlled. Unlike the fundamental boost converter, this converter has minimum ripples in its output due to the design of inductor. Also, an inductive filter is applied in the input of the topology to extract maximum energy. Therefore, the input and output of the topology is continuous. All of these beneficial features will make this structure suitable in renewable energy applications such as PV panels or in FC and etc. The rest of this paper is divided into four sections. The proposed converter topology is illustrated in section II. The calculation of the voltages and currents and ripples are provided in section III. Section IV is devoted to results given by simulation. Finally, section V is for the conclusion.

II. PROPOSED CONVERTER CONFIGURATION

The configuration comprises four diodes (D_1, D_2, D_3, D_4), five capacitors (C_1, C_2, C_3, C_4, C_5), two inductors (L_1, L_2), a single power switch Q and a resistive load. These elements are

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arranged in topology as shown in Fig.1 which provides a high voltage gain ratio step-up converter with continuous input and output powers.

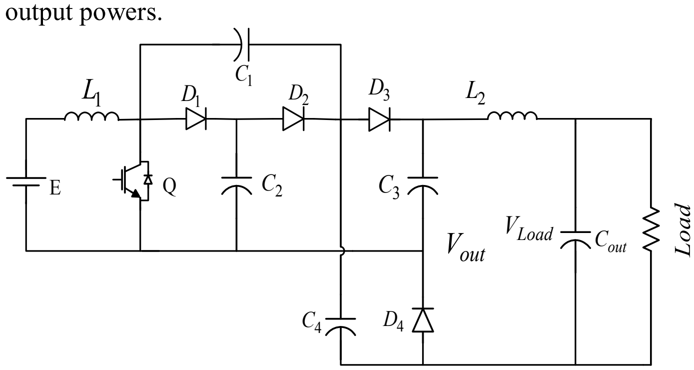


Fig. 1. proposed converter configuration

By assuming ideal behaviour of the main power switch, four states of operations are considered for the proposed converter. Relevant typical time-domain waveforms of each period is displayed in Fig. 2.

State 1 [0• t •t_1]: In this period of time, the main power switch Q is turned ON. The input current starts to magnetize the inductor L_1. The diodes D_3 and D_4 are turned off. The voltage across the C_2 stands as equal to the diode D_1 inversely and turn it off. A current flows through C_2, D_2, C_1 and Q which transmits a part of energy stored in C_2 to C_1. This process continues until the voltage of the capacitors C_1, C_2 is equal. At this time, t_1, D_2 turns off.

State 2 [t_1• t•t_2]: All diodes are OFF during this time interval. The inductor L_1 is still charging. The capacitors C_1, C_3 and C_4 feed the output load. Therefore, during this time interval, C_3 and C_4 discharges and C_1 charges while the voltage of the C_2 remained unchanged.

State 3 [t_2• t•t_3]: The power switch Q, the diodes D_3 and D_4 turn OFF at t_2. So, the output load is fed by the capacitors C_3 and C_4. The current path of the input inductor changes and starts to demagnetize it. Two paths exist for this current. The first path is through the C_2 and D_1 and the second is provided by the capacitors C_1 and C_3. According to the voltage across diode D_1, the second path is chosen. This current discharges C_1. Since the voltage of the C_2 does not change in this period, the reverse voltage for D_2 decreases. This process continues until it (the voltage of D_2) falls to zero at t_3.

State 4 [t_3• t•t_4]: In this time interval, the condition of power switch, the diodes D_2, D_3 and D_4 remain unchanged while D_1 turns ON. Hence, part of the current of L_1 passes thought C_2 and D_1. Hereinafter, C_1 discharges while C_2, C_3 and C_4 charges. This process continues till the power switch turns ON. The equivalent circuit and the current paths for each state are shown in Fig. 3.

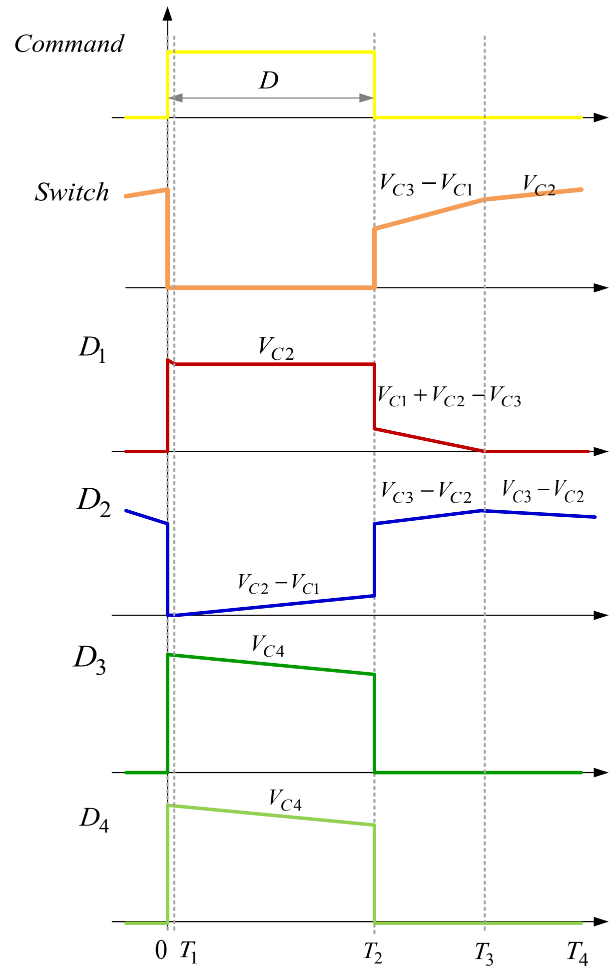
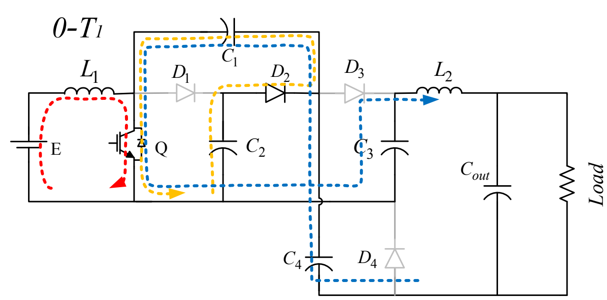
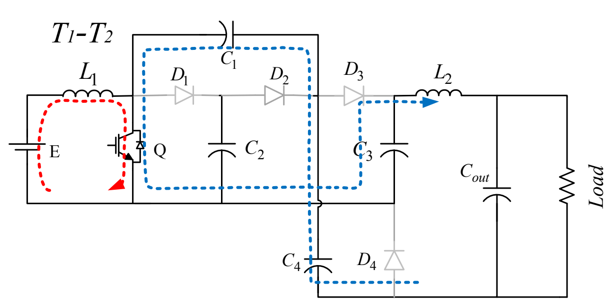


Fig. 2. Drawn typical waveforms for the presented converter



(a)



(b)

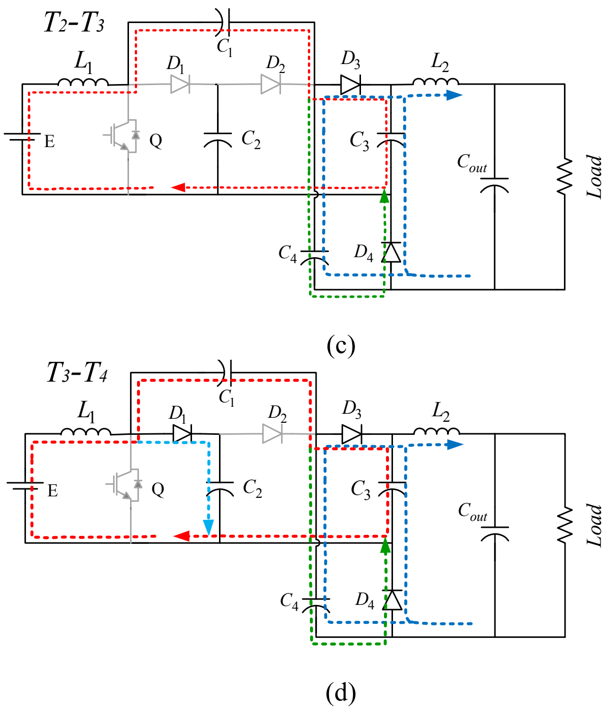


Fig. 3. Proposed converter circuit in four states of operations in the periods of: (a) [0• t •t_1], (b) [t_1• t•t_2], (c) [t_2• t•t_3] and (d) [t_3• t•t_4].

III. Calculation of Voltages, Currents and Ripples

A. Voltage Calculations

Considering that the switching frequency is high, the voltage ripples for all capacitors are negligible. Therefore, all of the capacitors voltages are assumed to be constant. Subsequently, the voltage for all inductors can be determined in two modes of operation as follows:

Mode 1 [0• t • DT$_s$]: The power switch is conducting during this time of performance. Therefore, the voltage across the inductors can be given as:

$$V_{L1}=E \tag{1}$$

$$V_{L2}=V_{C3}+V_{C4}-V_{C1}-V_{out} \tag{2}$$

Mode 2 [DT$_s$ • t •T$_s$]: The power switch is in the OFF mode in this time interval. Hence, the value of voltage for each inductor can be determined as:

$$V_{L1}=V_{C3}-V_{C1}-E \tag{3}$$

$$V_{L2}=V_{C3}-V_{out} \tag{4}$$

Now, the volt-sec balance is applied on the input and output inductors:

$$<V_{L1}>=\frac{1}{T_s}\left[\int_0^{DT_s} Edt+\int_{DT_s}^{T_s}(V_{C3}-V_{C1}-E)dt\right]=0 \tag{5}$$

$$<V_{L2}>=\frac{1}{T_s}\left[\int_0^{DT_s}(V_{C3}+V_{C4}-V_{C1}-V_{out})dt+\int_{DT_s}^{T_s}(V_{C3}-V_{out})dt\right]=0 \tag{6}$$

To calculate the voltage for all capacitors, the equations (5)-(6) are solved. The results are given by:

$$\begin{cases} V_{C1}=V_{C2}=\dfrac{E}{1-D} \\ V_{C3}=V_{C4}=\dfrac{2E}{1-D} \end{cases} \tag{7}$$

Therefore, the ratio of output to input voltage for the proposed converter in continuous conduction mode (CCM) is extracted by the help of the equations (7) which can be written a follows:

$$V_{out}=\frac{2+D}{1-D}E \tag{8}$$

According to the equation (8), the voltage gain ratio is considerably increased in this converter in compare with a fundamental boost converter.

The voltage across the diodes D_1, D_3 and D_4 can be determined during ON state of the main power switch:

$$\begin{cases} V_{D1}=V_{C2}=\dfrac{E}{1-D}=\dfrac{V_{out}}{2+D} \\ V_{D3}=V_{C3}-V_{C1}=\dfrac{E}{1-D}=\dfrac{V_{out}}{2+D} \\ V_{D4}=V_{C4}-V_{C1}=\dfrac{E}{1-D}=\dfrac{V_{out}}{2+D} \end{cases} \tag{9}$$

Consequently, when the power switch is OFF, The power switch voltage stress and that of D_2 can be obtained as:

$$\begin{cases} V_{D2}=V_{C3}-V_{C2}=\dfrac{E}{1-D}=\dfrac{V_{out}}{2+D} \\ V_{switch}=V_{C3}-V_{C1}=\dfrac{E}{1-D}=\dfrac{V_{out}}{2+D} \end{cases} \tag{10}$$

B. Current Calculations

Likewise, the same procedure is made for calculation of current of the capacitors. Considering the power switch is ON, the capacitor equations can be derived by applying KCL on the proposed converter circuit which are given as:

$$\begin{cases} i_{c1}=i_{L2}-i_{c2} \\ i_{c3}=-i_{L2} \\ i_{c4}=i_{L2}-i_o=i_{c3} \\ i_{cout}=i_{L2}-i_o \end{cases} \tag{11}$$

Consequently, the equations of currents when the power switch is OFF can be obtained as:

$$\begin{cases} i_{c1}=i_{c2}-i_{L1} \\ i_{c2}=i_{L1}-i_{c3}-i_{c4} \\ i_{c3}=i_{c4} \\ i_{cout}=i_{L2}-i_o \end{cases} \tag{12}$$

Using the ampere-second balance law on equations (11-12) provides the average value of current through the inductors L_1 and L_2. Thence, we have:

$$\begin{cases} i_{L1} = \dfrac{2+D}{1-D} i_o \\ i_{L2} = i_o \end{cases} \tag{13}$$

As it can be seen, the input inductor indicates the input current for the proposed converter and its current demonstrates the current gain ratio of the proposed converter. Thence the current gain in CCM can be written as follows:

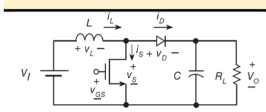
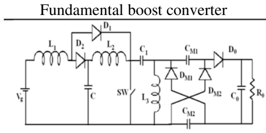
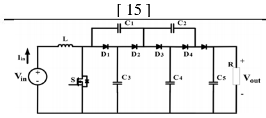
$$M_{CCM} = \frac{i_{in}}{i_o} = \frac{i_{L1}}{i_o} = \frac{2+D}{1-D} \tag{14}$$

By considering f_s as arbitrary value for frequency and the current ripple of each inductor can be determined by:

$$\begin{cases} \Delta i_{L1} = \dfrac{DV_{L1}}{L_1 f_s} = \dfrac{DE}{L_1 f_s} \\ \Delta i_{L2} = \dfrac{DV_{L2}}{L_2 f_s} = \dfrac{DE}{L_1 f_s} \end{cases} \tag{15}$$

It is of Interest to provide a comparison among the proposed converter and other relevant structures. Hence, some topologies are given in Table I. As all it is clear, an important advantage for this converter is the acquisition of high voltage gain ratio in company with continuous input and output power. Also only two inductor have used where decreases the costs.

TABLE I. SUMMARIZED INFORMATION FOR THE PROPOSED CONVERTER AND OTHER RELEVANT CONVERTERS

References	Number of Elements	Voltage gain	Continuous input current	Continuous output current
 Fundamental boost converter	1 Switch 1 Diode 1 Capacitor 1inductor	$\frac{1}{1-D}$	YES	NO
 [15]	1 Switch 5 Diodes 5Capacitors 3 Inductors	$\frac{2-D}{(1-D)^2}$	YES	NO
	1 Switch 5 Diodes 5Capacitors 1 Inductor1	$\frac{3}{1-D}$	YES	NO
Proposed converter	1 Switches 4 Diodes 5Capacitors 2 Inductors	$\frac{2+D}{1-D}$	YES	YES

IV. SIMULATIONS

To support the theoretical equation for the proposed converter, simulation results are provided in MATLAB. According to the parameter values considered based on ripples of components in Table II, 50% of duty cycle is selected.

Table II. SIMULATION PARAMETERS

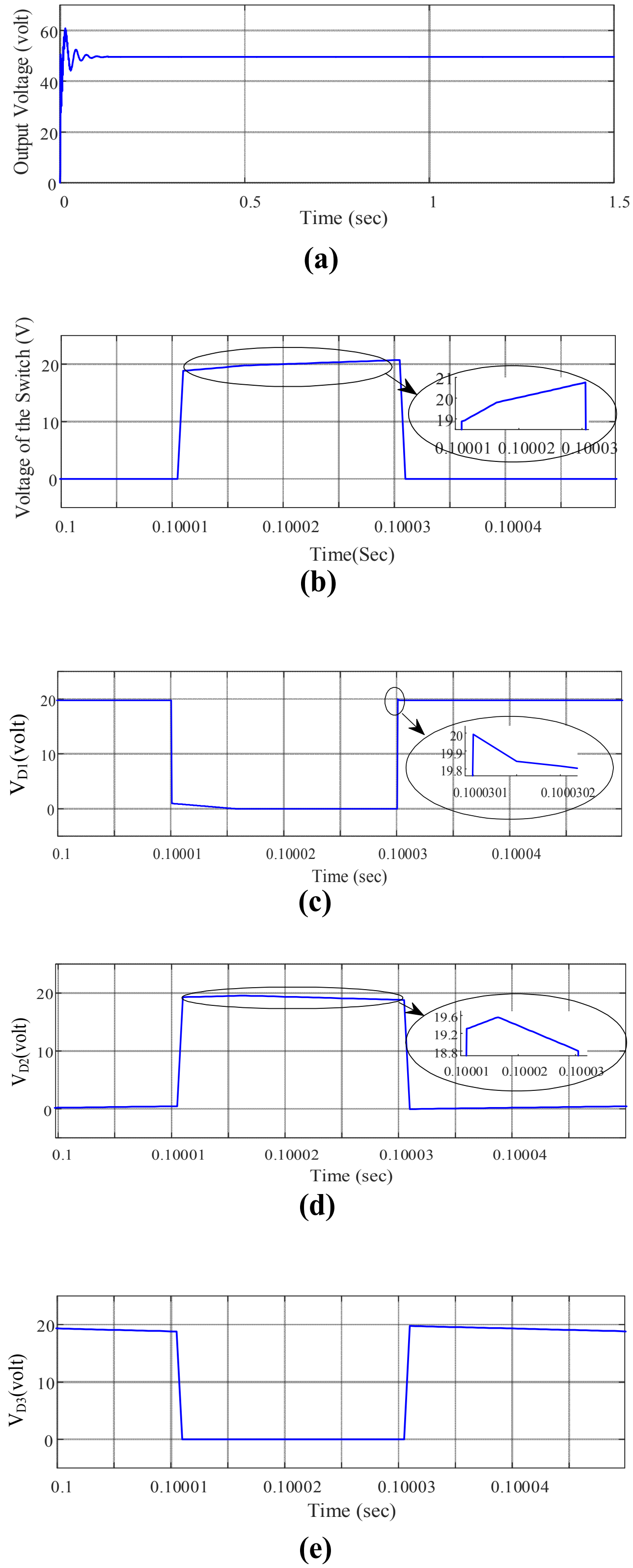
Input Voltage	**10 Volt**
Output Voltage	**50 volt**
Duty Cycle	**50%**
L_1	**1.5 mH**
L_2	**0.75 mH**
C_1, C_2, C_3, C_4	**200 µF**
C_{out}	**470 µF**
Frequency	**33 KHz**
Output Load	**20 •**

The input voltage for the proposed converter is converted from 10v to 50v at the switching frequency of 33 kHz. As depicted in Fig. 4 (a), the simulated result for output load voltage V_o is 50v which is consistent with the (8).

With due attention to the (10) and (11), the voltage stress across the blocked power switch is obtained as 20v. Moreover, the voltage stress across all of the diodes $V_{D1\text{-}5}$ are all equal to 20v. As displayed in Fig. 4 (b)-(f), the relevant waveforms can reconfirm the theoretical equations and simulations. The voltage of inductive filter V_{L1} displayed in Fig. 4 (g) is equal to 10v during the ON state of the main power switch. Also when the power switch is OFF, its voltage becomes -10v. The derived equations in (1) and (3) are in agreement with these waveforms respectively.

For fundamental boost converter, the output current flows through a diode which turns ON and OFF during a period which is discontinuous. But, in this converter, the output port connected to the load is continuous. The input current (I_{L1}) of the proposed converter is continuous with due attention to the given waveform in Fig. 4 (h). Subsequently, the current waveform of the output inductor (I_{L2}) in Fig. 4 (i) verifies this concept that it does not meet the zero axis.

As a sample, the voltage across the capacitor C_2 (V_{C2}) is given in Fig. 4 (j) which is calculated as 20v according to (7). It can be seen that the both theoretical and mathematical result are as the same. Generally, mathematics implies vividly that the all of the waveforms are coincided with the theoretical equation and supports the applicability of the proposed converter.



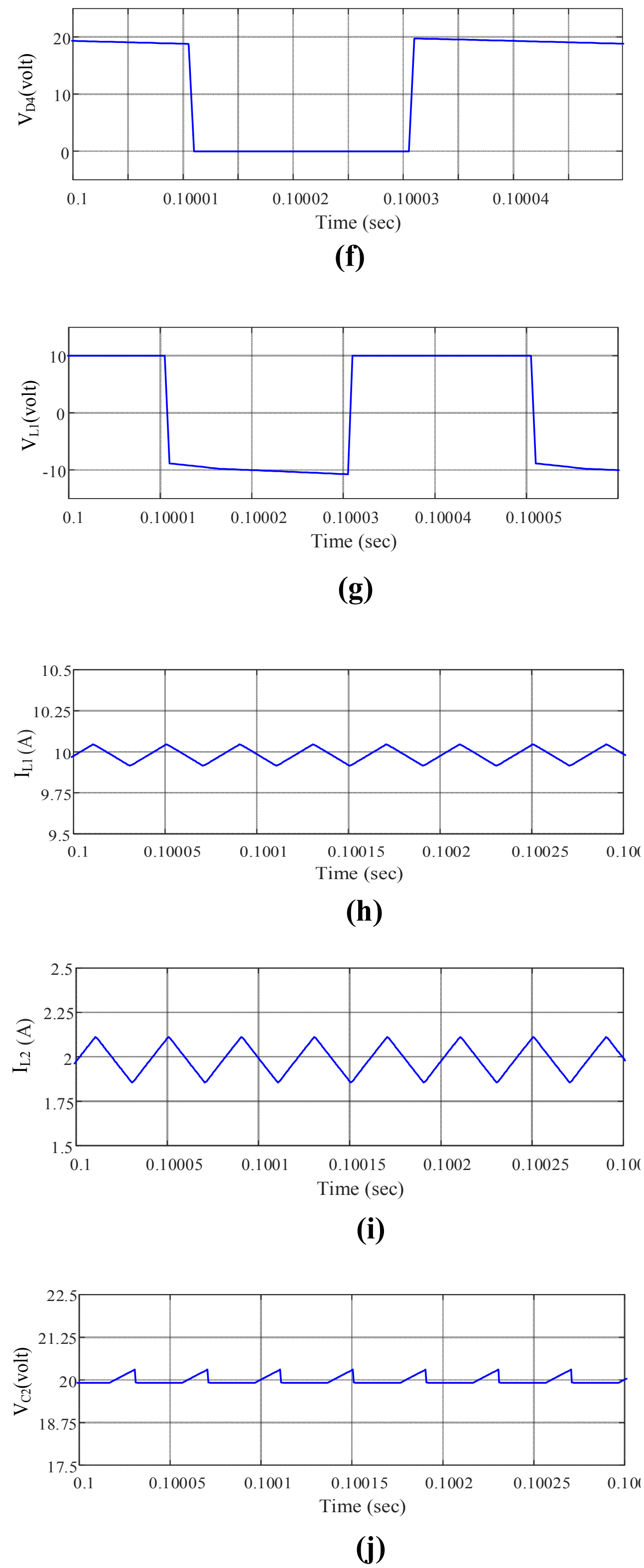


Fig. 4. Simulation results for the proposed converter based on parameter values summarized in table 1. (a) Output load voltage V_o (b)Voltage stress across the power switch V_{switch} (c) V_{D1} (d) V_{D2} (e) V_{D3} (f) V_{D4} (g) V_{L1} (h) inductor current I_{L1} (i) Inductor current I_{L2} (j) capacitor voltage

V. CONCLUSION

In this work, a novel architecture for a high Gain single-switch DC-DC boost converter with continuous input and output current is introduced. How to increase the voltage, time intervals of ON/OFF mode of the main power switch and all of the diodes are illustrated. In this topology the DC voltage transfer ratio is improved without using any isolated transformers or coupled inductors. Compared to the conventional boost converter, this converter offers much lower voltage stress across its power switch which contributes to the much higher reliability in practice. Also, the voltage stresses across all diodes are same as voltage power switch which are considerably low. It should be noted that due to the presence of the inductor on the input and output of the converter, the proposed converter offers much proper choice to be used in applications such as the solar cells and the FCs. Simulation results in MATLAB Simulink verifies the theoretical concepts and derived equations and waveforms.

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