High-Gain Buck-Boost Converter Suitable for Renewable Applications

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***Abstract*—This paper introduces a novel topology of buck-boost converter. In comparison to the traditional buck-boost converter, the voltage ratio of the proposed topology is high. Despite the high voltage gain of the quadratic buck-boost converters in step-up mode, the voltage ratio of the proposed converter in a specified duty cycle is approximately 2 times of the quadratic buck-boost converters in step up mode. Continuity of the input current is the other advantages of the proposed converter. Thus, the proposed topology is appropriate for renewable applications. Moreover, the output current of the proposed converter is continuous. The introduced topology is functioning in continuous current mode (CCM); hence, all principle operations and steady state analysis are discussed in CCM. Eventually, a simulation studies is carried out in PLECS to verify performances of the offered topology.**

***Index Terms*—Continuous input current, Continuous output current, DC-DC buck-boost topology, High gain converter, Renewable energy sources.**

I. Introduction

In recent years, electricity demand of consumers is increased. Since, in the conventional power plants, the major sources of power generations are fossil fuels, some concerns about climate changes, global warming and depletion of fossil fuels is created. One solution to address these concerns is to replace distributed generations (DGs) instead of conventional power plants. Especially, the situation has become suitable for pollution-free energy production to take part in generating electricity. Therefore, attention to penetrate high level of renewable energy sources in the power system has increased [1].

The output powers of the renewable energy sources are dependent on the climate as well as the output voltage of them is low [2]. Thus, to utilize the power of renewable sources, the amplitude of voltage should be increased to the demanded level [3]. Moreover, output voltage is not steady and the source can not be directly connected to the load [4], [5]. Utilizing of the generated power from renewable energy sources is done by power electronic devices and converters. Since, the amplitude of the output voltage of the renewable energy sources is low, high gain dc-dc converters with continuous input current are needed. Therefore, converters with these two features are used in renewable energy applications [8]. Moreover, dc-dc converters are used in vehicles, communication systems, power factor correction and many other fields [7].

Many researches about dc-dc converters and various fields of power electronic have been done and have become an absorbing topic for researchers. To overcome challenges such as low voltage gain, lots of typologies and techniques have been introduced. In theory, infinite voltage ratio can be achieved with utmost close duty cycle to one. However, close duty cycle to one decreases efficiency. Therefore, when the required boosting voltage gain ratio is more than four, traditional boost converters are not used [8]–[11].

Extreme voltage ratio can be reached by employing the voltage lift technique, with Luo converters; however, complexity of topology, volume, cost and losses increase at the same time [12]. Diode-capacitor multiplier is an other technique to combine the conventional converter with mentioned structure. In spite of high voltage gain, the existence of inrush currents and increasing the number of diodes, prevents designers from using this structure. therefore, high number of diodes decreases the efficiency of the mentioned technique [13].

In [14] a buck-boost converter with extreme voltage ratio has been proposed. In spite of high voltage ratio, input and output current of the offered toplogy in [14] are not continuous; therefore, it can not be used in renewable energy sources and also current stress of the output capacitor increases. In [15] an other high gain buck-boost converter has been introduced. Current stress of the load terminal capacitor can be decreased by the continuity of output current. In this study, a buck-boost converter with continuous input and output current has been introduced. The proposed converter is combination of a SEPIC and CUK converter ; therefore, two inductore have been used in input part. Moreover, to obtain the continuity of the output current an other inductor have been used in the output part. Different aspects of the introduced converter have been explained as follow:

- Continuity of the input current makes the proposed topology appropriate for renewable applications.
- Continuity of the output current has reduced the current stress of the load terminal.
- Voltage ratio of the offered topology is approximately two times of the quadratic buck-boost converter with the duty cycle in high step mode.

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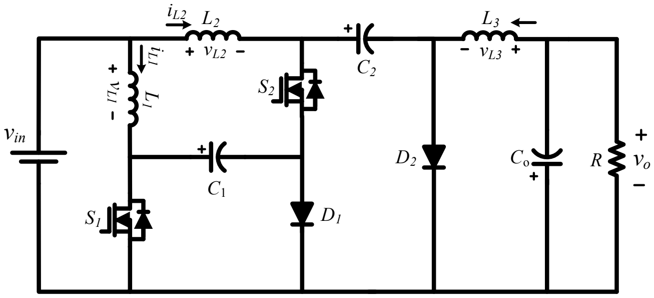

Fig. 1. The introduced high gain buck-boost topology.

II. OFFERED CONVERTER

The offered topology consists of three inductors, L_1, L_2 and L_3, three capacitors, C_1, C_2 and C_o, two power switches S_1 and S_2 and two diodes, D_1 and D_2 which is illustrated in Fig.1. The power switches of the offered topology are concurrently turned ON and OFF.

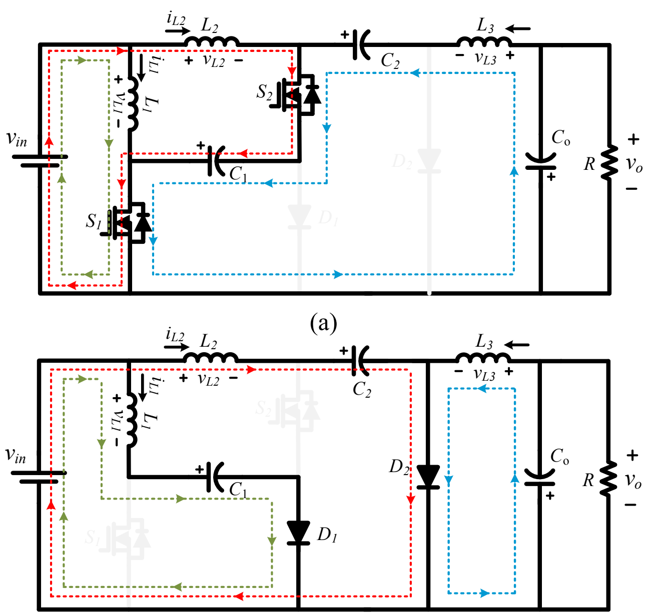

Fig. 2. The introduced high gain buck-boost topology, (a) procedure 1, and (b) procedure 2.

To ease analysis of the offered topology, some remarks are brought up as follow:

- All components, switches, diodes, inductors and capacitors, are ideal.
- All analysis are done in steady state and the offered topology is functioning in continuous current mode (CCM).

The operating modes of the offered topology are addressed as below:

1) Mode 1: During this procedure, the power switches $S_1$and S_2 are turned ON simultaneously while D_1 and D_2 are reversed biased; therefore, they are turned OFF. Moreover, the capacitor C_1 and C_2 are discharged in this mode. The path of the flowed current of the inductors are represented in Fig.2 (a). The voltage across the inductors can be expressed as:

$$\begin{cases} v_{L_1} = v_{in} \\ v_{L_2} = v_{c_1} + v_{in} \\ v_{L_3} = v_{c_2} + v_{c_1} - v_o \end{cases} \tag{1}$$

Moreover, in this mode, current of the capacitors can be found as :

$$\begin{cases} i_{c_1} = -i_{L_2} - i_{L_3} \\ i_{c_2} = -i_{L_3} \\ i_{c_o} = i_{L_3} - \frac{v_o}{R} \end{cases} \tag{2}$$

2) Mode 2: During this procedure, the power switches S_1 and S_2 are turned OFF simultaneously and diodes D_1 and D_2 are turned ON. The path of the flowed current of inductors in this mode are illustrated in Fig.2 (b).
In this mode, voltage across the inductors, can be calculated as:

$$\begin{cases} v_{L_1} = v_{in} - v_{c_1} \\ v_{L_2} = v_{in} - v_{c_2} \\ v_{L_3} = -v_o \end{cases} \tag{3}$$

The capacitor currents can be written as:

$$\begin{cases} i_{c_1} = i_{L_1} \\ i_{c_2} = i_{L_2} \\ i_{c_o} = i_{L_3} - \dfrac{v_o}{R} \end{cases} \tag{4}$$

Voltage-second balance principle of inductors concludes that the average voltage of the inductors in a switching period is zero. Therefore, the voltage of the capacitors C_1, C_2 and output capacitor can be calculated as:

$$\begin{cases} V_{c_1} = \dfrac{V_{in}}{1-D} \\ V_{c_2} = \dfrac{1}{(1-D)^2} V_{in} \\ V_o = \dfrac{D(2-D)}{(1-D)^2} V_{in} \end{cases} \tag{5}$$

Finally, the voltage ratio of the offered topology can be written as:

$$M = \frac{V_o}{V_{in}} = \frac{D(2-D)}{(1-D)^2} \tag{6}$$

From (6), the voltage gain which is built up in this converter is more than the traditional buck-boost converter. Comparing voltage ratio of traditional buck-boost topology and the offered

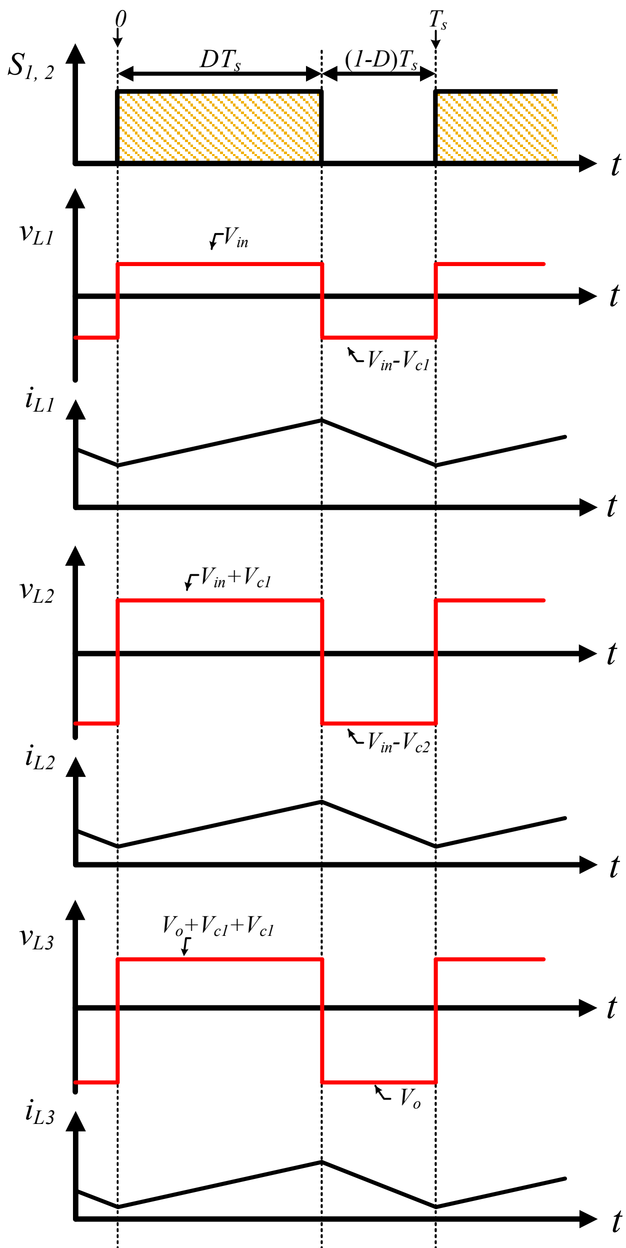

Fig. 3. Voltage and current of inductors.

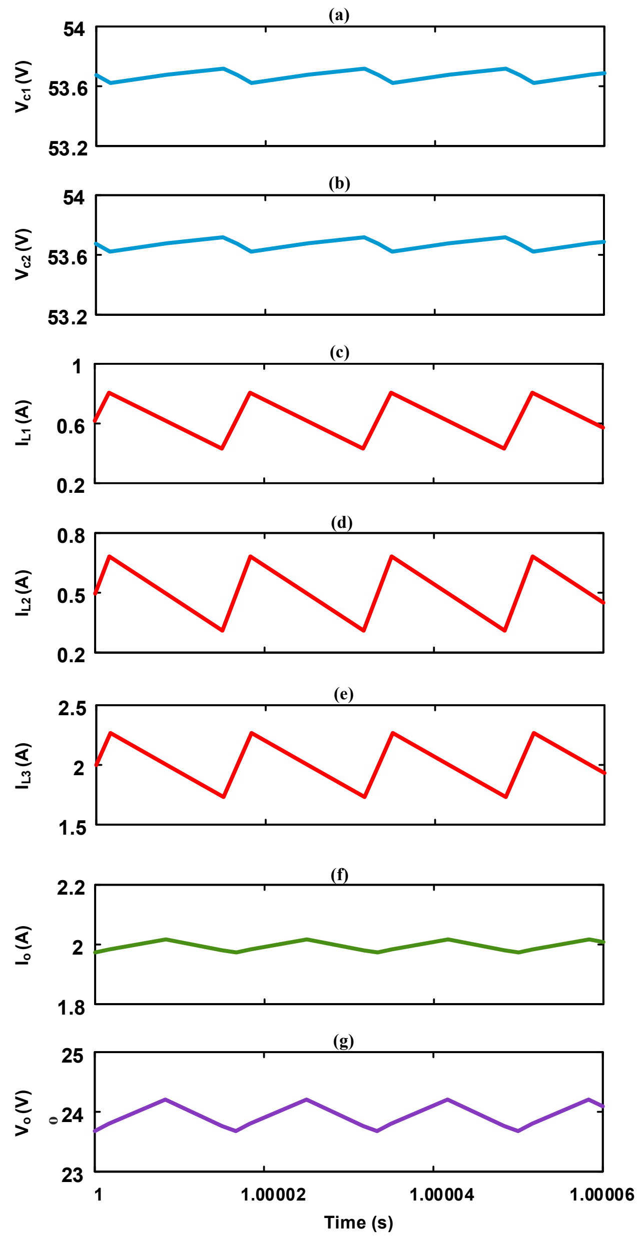

Fig. 4. Simulation result of offered topology as a buck converter.

topology indicates us that the new one can operate in a broad span of output voltage. If the duty cycle is less than 0.29, the offered topology operates as a buck converter; otherwise, it operates as boost converter. It is obvious that the offered topology can operates in a broad span of duty cycle in high step mode.

Average current of the capacitors are zero; therefore, inductors current can be explained by applying current-second balance principle to capacitors as follow :

$$\begin{cases} I_{L_1} = \dfrac{D}{(1-D)^2}\dfrac{V_o}{R} \\ I_{L_2} = \dfrac{D}{1-D}\dfrac{V_o}{R} \\ I_{L_3} = \dfrac{V_o}{R} \end{cases} \tag{7}$$

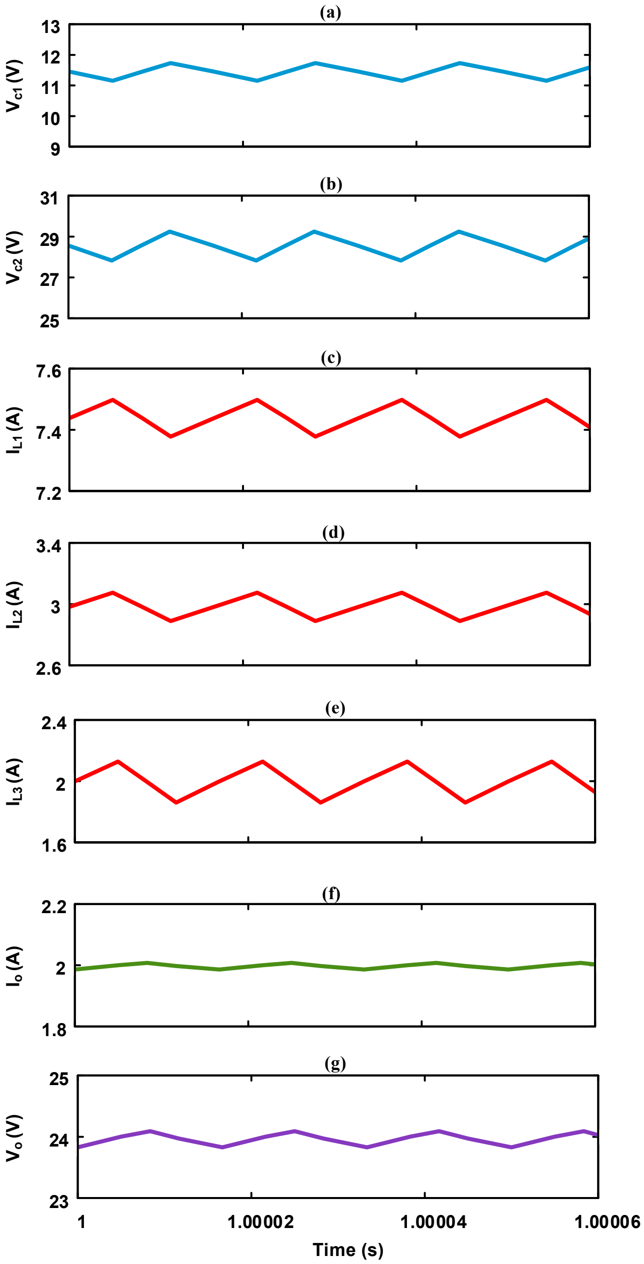

Fig. 5. Simulation result of the offered topology as a boost converter.

A. voltage stress of semiconductor devices

From Model 1, the voltage stress of diodes can be expressed as follows:

$$\begin{cases} V_{D_1} = \dfrac{1}{1-D}V_{in} \\ V_{D_2} = \dfrac{2-D}{(1-D)^2}V_{in} \end{cases} \tag{8}$$

Voltage stress of switches can be calculated in the proposed converter as follows:

$$\begin{cases} V_{S_1} = \dfrac{1}{1-D}V_{in} \\ V_{S_2} = \dfrac{1}{\left(1-D\right)^2}V_{in} \end{cases} \tag{9}$$

B. The current stress of switches

The current stress of power switches and diodes in the offered topology can be written as:

$$\begin{cases} I_{S_1} = \dfrac{D}{1-D}\dfrac{V_o}{R} \\ I_{S_2} = \dfrac{D}{(1-D)^2}\dfrac{V_o}{R} \end{cases} \tag{10}$$

$$\begin{cases} I_{D_1} = \dfrac{D}{1-D}\dfrac{V_o}{R} \\ I_{D_2} = \dfrac{V_o}{R} \end{cases} \tag{11}$$

C. Ripples of inductor current and capacitor voltage

Current ripple of inductors can be calculated as:

$$\begin{cases} \Delta i_{L_1} = \dfrac{D}{L_1 f_s}V_{in} \\ \Delta i_{L_2} = \dfrac{D(2-D)}{L_2 f_s}V_{in} \\ \Delta i_{L_3} = \dfrac{1-D}{L_3 f_s}V_o \end{cases} \tag{12}$$

All inductors must satisfy in following inequalities to make sure that the converter operates in CCM mode :

$$\begin{cases} L_1 > \left(1-D\right)^4 \dfrac{R}{2D(2-D)f_s} \\ L_2 > \left(1-D\right)^3 \dfrac{R}{2Df_s} \\ L_3 > (1-D)\dfrac{R}{2f_s} \end{cases} \tag{13}$$

Current ripple of the inductors concludes all expressed inequalities in the last section.

Voltage ripple of capacitor can be explained as:

$$\begin{cases} \Delta v_{c_1} = \dfrac{DV_o}{(1-D)RC_1 f_s} \\ \Delta v_{c_2} = \dfrac{DV_o}{f_s C_2 R} \\ \Delta v_{c_o} = \dfrac{(1-D)V_o}{8L_3 C_O f_s^2} \end{cases} \tag{14}$$

Voltage ripple of the capacitors is an essential factor to define the capacitors of the proposed converter.

III. Simulation Result

The software which is used to analyzing the proposed buck-boost converter is PLECS which is usually used to analyze

TABLE I
SIMULATION COMPONENTS OF THE OFFERED TOPOLOGY.

Parameters	buck Procedure	boost Procedure
V_{in}	43 V	4.6 V
V_O	24 V	24 V
f_s	60 kHz	60 kHz
R	12 Ω	12 Ω
L_1	0.38 mH	0.38 mH
L_2	0.86 mH	0.86 mH
L_3	0.6 mH	0.6 mH
C_1	86 μF	86 μF
C_2	14 μF	14 μF
C_3	2.1 μF	2.1 μF

power electronics systems. The designed parameters are expressed in Table I. All components are assumed ideal and the theoretical calculations are done for this mode.

The simulation results in buck procedure are illustrated in Fig.4 while the duty cycle in this mode is 0.2. Figs.4 (a)-(c) show the inductor currents I_{L_1}, I_{L_2} and I_{L_3}, respectively. Continuiuty of input current is obvious. The voltage of capacitor C_1, C_2 and C_O are depicted in Figs. 4 (e)-(g), respectively. The proposed topology has converted 4.6 V of input source to 24 V at output port.

The simulation results in step-up are depicted in Fig.5 while the duty cycle of step-up mode is about 0.6. Figs. 5 (a)-(c) show the inductor currents I_{L_1}, I_{L_2} and I_{L_3}, respectively. Continuity of the input current is obvious. The voltage of capacitor C_1, C_2 and C_O are illustrated in Figs. 5 (e)-(g), respectively. It can be understood that the offered converter has transformed 43 V of input source to 24 V at output port.

IV. CONCLUSION

In this study, a dc-dc buck-boost converter with wide range of output voltage has been offered. Continuity of the input current decrease the current stress on the source and makes it suitable for using in the renewable energy sources. Therefore, intermittent renewable energy sources with low voltage output can be connect to the power system by this converter. Moreover, it can be understood that the offered topology can operate as buck and boost converter. Finally, in order to justify the validity of the offered, some simulation studies are performed.

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