DESIGN OF NOVEL NON- ISOLATED BUCK-BOOST CONVERTER FOR RENEWABLE ENERGY SYSTEMS

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Abstract: This paper proposes a new transformerless buck-boost converter with a basic structure. The voltage gain of the suggested buck-boost converter is squared times that of the typical buck-boost converter, and the output voltage polarity is positive. Because of these characteristics, it can produce a larger range of good results. The suggested buck-boost converter's two power switches are synchronous. Two inductors are magnetised and two capacitors are discharged during the switch-on period in the continuous conduction mode (CCM), whereas two inductors are demagnetized and two capacitors are charged during the switch-off period. The operational concepts for the proposed CCM converter are described in great depth. To validate the effectiveness of the proposed buck-boost converter, MATLAB simulations are provided.

Index Terms— **New transformerless buck-boost converter, positive output voltage, continuous conduction mode.**

I. INTRODUCTION

As is well known, switching mode power supply is the core of modern power conversion technology, which is widely used in electric power, communication system, household appliance, industrial device, railway, aviation and many other fields [1-2]. As the basis of switching mode power supply, converter topologies attract a great deal of attention and many converter topologies have been proposed. Buck converter and boost converter have the simple structure and high efficiency. However, due to the limited voltage gain, their applications are restricted when the low or high output voltage are needed [3]. Luo converters can obtain high voltage gain by employing the voltage lift technique, but the topological complexity, cost, volume, and losses increase at the same time [4-6]. Interleaved converters can achieve high step-up or step-down conversion ratio with low voltage stress, while their operating mode, converter structure and control strategy are complicated [7-10].

Quadratic converters can achieve the voltage gain of cascade converters with fewer switches, however, the efficiency of these converters are low [11-12]. Additional, some switched networks are added into the basic converters to obtain the high voltage step-up or step-down gain, at the price of complicating construction and increasing cost [13-23]. Compared with the above mentioned converter topologies who can only step-up or step-down voltage, the voltage bucking/boosting converters, which can regulate output voltage under wider range of input voltage or load variations, are popular with the applications such as portable electronic devices, car electronic devices, etc. The traditional buck-boost converter with simple structure and high efficiency, as we all known, has the drawbacks such as limited voltage gain, negative output voltage, floating power switch, meanwhile discontinuous input and output currents. The other three basic non-isolated converters, Cuk converter, Sepic converter and Zeta converter which also have the peculiarity to step-up and step-down voltage, have been provided. However, the limits of the voltage gain along with other disadvantages in Cuk, Sepic, and Zeta converters are also non-ignorable. The quadratic buck-boost converter, proposed by Maksimovic and Cuk in [24], has one common-ground power switch, meanwhile it can achieve the voltage gain $D^2/(1-D)^2$.

However, due to the diodes D1 and D2 clamp the output voltage to the input voltage while the duty cycle is bigger than 0.5, so that this converter can only work in step-down mode. By combining KY converter and the traditional synchronously rectified buck converter, Hwu and Peng proposed a new buck-boost converter [25] which can realize the continuous output current, positive output voltage, continuous conduction mode (CCM) operation all the time, and no right-half plane zero. Unfortunately, its voltage gain of two multiplies the duty cycle isn’t sufficiently high or low in the situation where the converter needs to operate in a wide range of output voltage. Also, based on the Cuk converter, a new buck-boost converter, which has the low output voltage ripple, minimal radio frequency interference and one common-ground power switch, is proposed in [26]. However, as a seventh-order circuit, the converter has complex construction, and both its input terminal and output terminal don’t share the same ground. Besides, the voltage gain is still limited. In [27], a boost-buck cascade converter, aggregating two separated converters with current source and current sink, is applied for the thermoelectric generator. Nevertheless, the voltage gain of this cascade converter is also constrained. Especially, in order to obtain high voltage step-up or step-down gain, these converters must be operating under extremely high or low duty cycle, and this point is too hard to realize due to the practical constraints. Hence, exploring new topology of buck-boost converter to overcome the drawbacks of the conventional ones for satisfying the increasingly requirements in industrial applications is very important and valuable.

In this study, by inserting an additional switched network into the traditional buck-boost converter, a new transformerless buck-boost converter is proposed. The main merit of the proposed buck-boost converter is that its voltage gain is quadratic of the traditional buck-boost converter so that it can operate in a wide range of output voltage, that is, the proposed buck-boost converter can achieve high or low voltage gain without extreme duty cycle. Moreover, the output voltage of this new transformerless buck-boost converter is common-ground with the input voltage, and its polarity is positive.

II. PROPOSED CONVERTER

Fig. 1 shows the circuit configuration of the new transformerless buck-boost converter, which consists of two power switches (S1 and S2), two diodes (D1 and D0), two inductors (*L*1 and *L*2), two capacitors (*C*1 and *C*0), and one resistive load *R*. Power switches S1 and S2 are controlled synchronously. According to the state of the power switches and diodes, some typical time-domain waveforms for this new transformerless buck-boost converter operating in CCM are
displayed in Fig. 2, and the possible operation states for the proposed buck-boost converter are shown in Fig. 3. For Fig. 3 (a), it denotes that the power switches S1 and S2 are turned on whereas the diodes D1 and D0 do not conduct. Consequently, both the inductor *L*1 and the inductor *L*2 are magnetized, and both the charge pump capacitor *C*1 and the output capacitor *C*0 are discharged. For Fig. 3(b), it describes that the power switches S1 and S2 are turned off while the diodes D1 and D0 conduct for its forward biased voltage. Hence, both the inductor *L*1 and the inductor *L*2 are demagnetized, and both the charge pump capacitor *C*1 and the output capacitor *C*0 are charged.

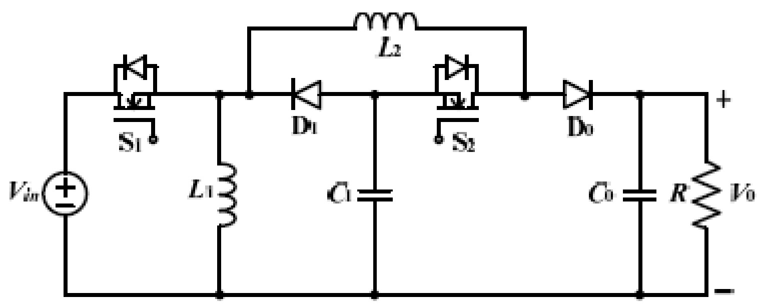

Fig. 1. Proposed transformerless buck-boost converter

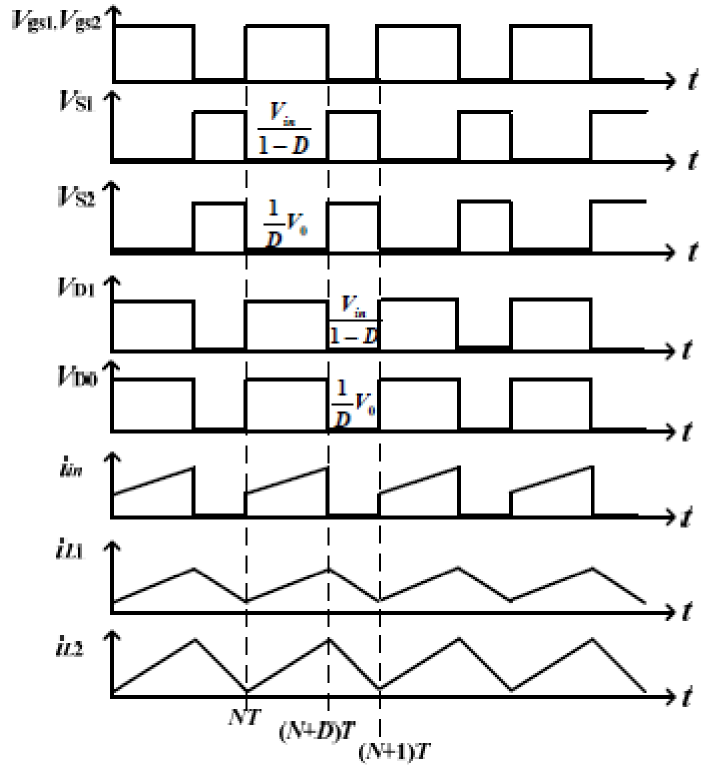

Fig. 2. Typical time-domain waveforms for the proposed buck-boost converter operating in CCM.

Here, in order to simplify the circuit analyses and deduction, we assumed that the converter operates in steady state, all components are ideal, and all capacitors are large enough to keep the voltage across them constant.

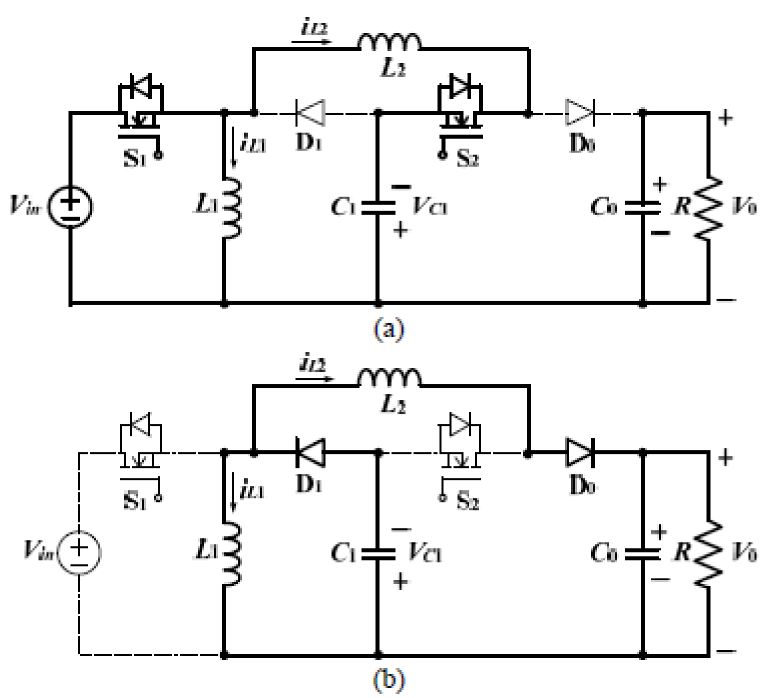

Fig. 3. Equivalent circuits of the proposed buck-boost converter in possible two states. (a) State 1. (b) State 2.

III. BASIC OPERATING PRINCIPLES AND ANALYSES

A. Operating principles

As shown in Fig. 3, there are two states, that is, state 1 and state 2, in the new transformerless buck-boost converter when it operates in CCM operation.

State 1 ($NT<t<(N+D)T$): During this time interval, the switches S1 and S2 are turned on, while D1 and D0 are reverse biased. From Fig. 3(a), it is seen that $L1$ is magnetized from the input voltage Vin while $L2$ is magnetized from the input voltage Vin and the charge pump capacitor $C1$. Also, the output energy is supplied from the output capacitor $C0$. Thus, the corresponding equations can be established as

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

$$V_{L2} = V_{in} + V_{C1}\,. \tag{2}$$

State 2 ($(N+D)T<t<(N+1)T$): During this time interval, the switches S1 and S2 are turned off, while D1 and D0 are forward biased. From Fig. 3(b), it is seen that the energy stored in the inductor $L1$ is released to the charge pump capacitor $C1$ via the diode D1. At the same time, the energy stored in the inductor $L2$ is released to the charge pump capacitor $C1$, the output capacitor $C0$ and the resistive load R via the diodes D0 and D1. The equations of the state 2 are described as follows

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

$$V_{L2} = -(V_{C1} + V_0)\,. \tag{4}$$

If applying the voltage-second balance principle on the inductor $L1$, then the voltage across the charge pump capacitor $C1$ is readily obtained from (1) and (3) as

$$V_{C1} = \frac{D}{1-D} V_{in}\,. \tag{5}$$

Here, D is the duty cycle, which represents the proportion of the power switches turn-on time to the whole switching cycle. Similarly, by using the voltage-second balance principle on the inductor $L2$, the voltage gain of the proposed buck-boost converter can be obtained from (2), (4), and (5) as

$$M = \frac{V_0}{V_{in}} = \left(\frac{D}{1-D}\right)^2. \tag{6}$$

From (6), it is apparent that the proposed buck-boost converter can step-up the input voltage when the duty cycle is bigger than 0.5, and step-down the input voltage when the duty cycle is smaller than 0.5.

The curves of the voltage gain against the duty cycle among these three converters are shown in Fig.4.

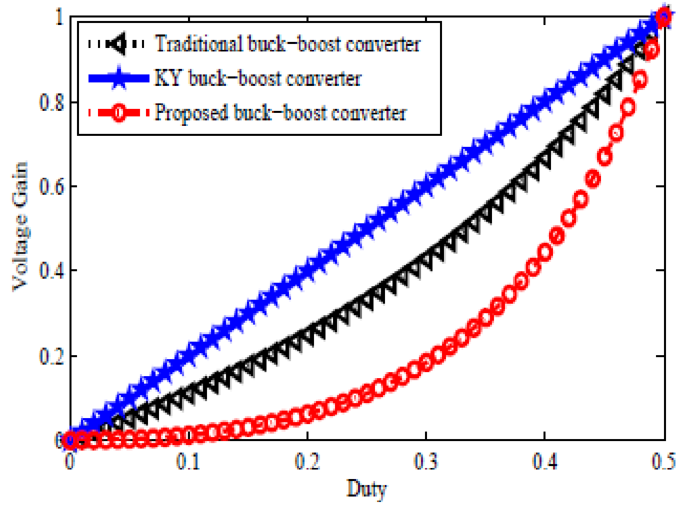

Fig. 4. Comparisons about the voltage gain among the traditional buck-boost converter, the KY buck-boost converter, and the proposed buck-boost converter. (b) Step-down mode.

IV. SIMULATIONS

Based on the MATLAB software and Fig. 1, the simulation circuit of the new transformerless buck-boost converter can be constructed for the PSIM simulations to confirm the aforementioned analyses in section III preliminary. Note that, circuit parameters here are chosen as: Vin=18V, fs=20kHz, D=0.4-0.6, $L1$=1mH, $L2$=3mH, $C1$=10μF, $C0$=20μF, R=30-150Ω. Fig. 5 shows the time-domain waveforms of the output voltage $v0$, the charge pump capacitor voltage $vC1$, the currents of the two inductors $L1$ and $L2$, and the driving signal vg for the new transformerless buck-boost converter operating in step-up mode when the duty cycle is 0.6. Since the two power switches conduct synchronously, only one driving signal vg is chose. From Fig. 5, one can obtain that the charge pump capacitor voltage $vC1$ is within (25.8V, 27.8V), the output voltage $v0$ is within (40.2V, 40.6V), the inductor current $iL1$ is within (0.07A, 0.61A), and the inductor current $iL2$ is within (0.45A, 0.90A). Also, the ripples of the inductor current $\Delta iL1$ and the inductor current $\Delta iL2$ are 0.54A and 0.45A, respectively. Additionally, the ripples of the two capacitors $\Delta vC1$ and $\Delta vC0$ are 2V and 0.4V, respectively. From the equations (5), (6), (17), (18), and (23)-(26), the theoretical results are $VC1$=27V, $V0$=40.5V, $IL1$=0.34A, $IL2$=0.68A, $\Delta iL1$=0.54A, $\Delta iL2$=0.45A, $\Delta vC1$=2V, $\Delta vC0$=0.4V, respectively.

For the proposed buck-boost converter operating in step-down mode when the duty cycle is choosing as 0.4, Fig. 6 displays the time-domain waveforms of the output voltage $v0$, the charge pump capacitor voltage $vC1$, the currents of the two inductors $L1$ and $L2$, and the driving signal vg. It is clearly seen that the charge pump capacitor voltage $vC1$, the output voltage $v0$, the inductor current $iL1$, and the inductor current $iL2$ are within (11.44V, 12.32V), (7.77V, 8.04V), (-0.33A, 0.03A) and (0.34A, 0.54A), respectively. Also, the ripples of the inductor current $\Delta iL1$ and the inductor current $\Delta iL2$ are 0.36A and 0.2A, respectively. And, the ripples of the two capacitors $\Delta vC1$ and $\Delta vC0$ are 0.88V and 0.27V, respectively. Similarly, the theoretical calculations from the equations (5), (6), (17), (18), and (23)-(26)

are $VC1$=12V, $V0$=8V, $IL1$=-0.15A, $IL2$=0.44A, $\Delta iL1$=0.36A, $\Delta iL2$=0.2A, $\Delta vC1$=0.89V, $\Delta vC0$=0.27V, separately.

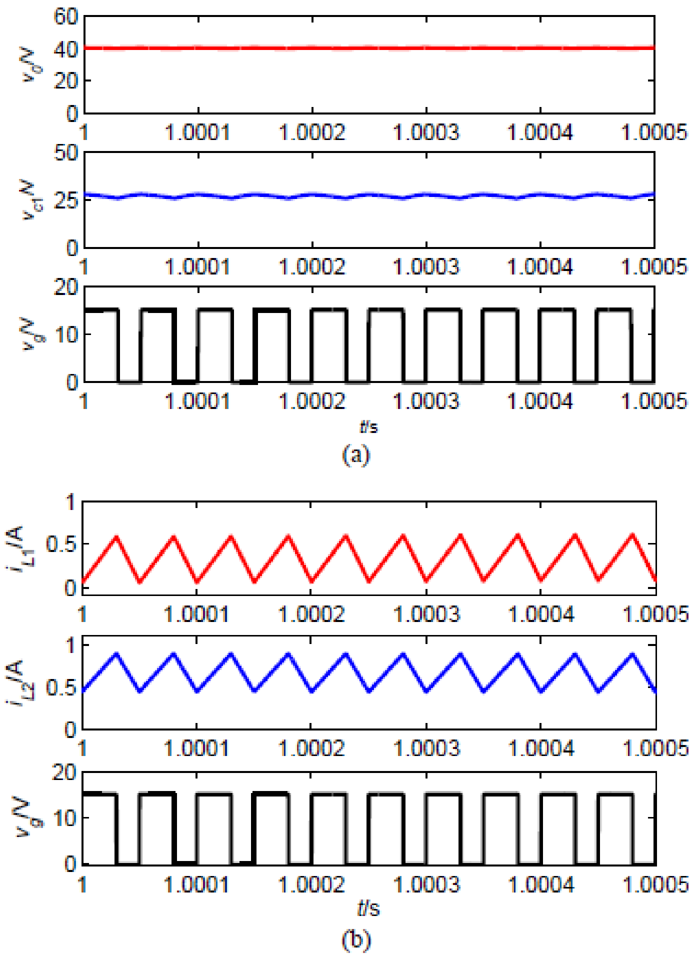

Fig. 5. PSIM simulations for the proposed buck-boost converter operating in step-up mode. (a) $v0$, $vC1$, and vg. (b) $iL1$, $iL2$, and vg.

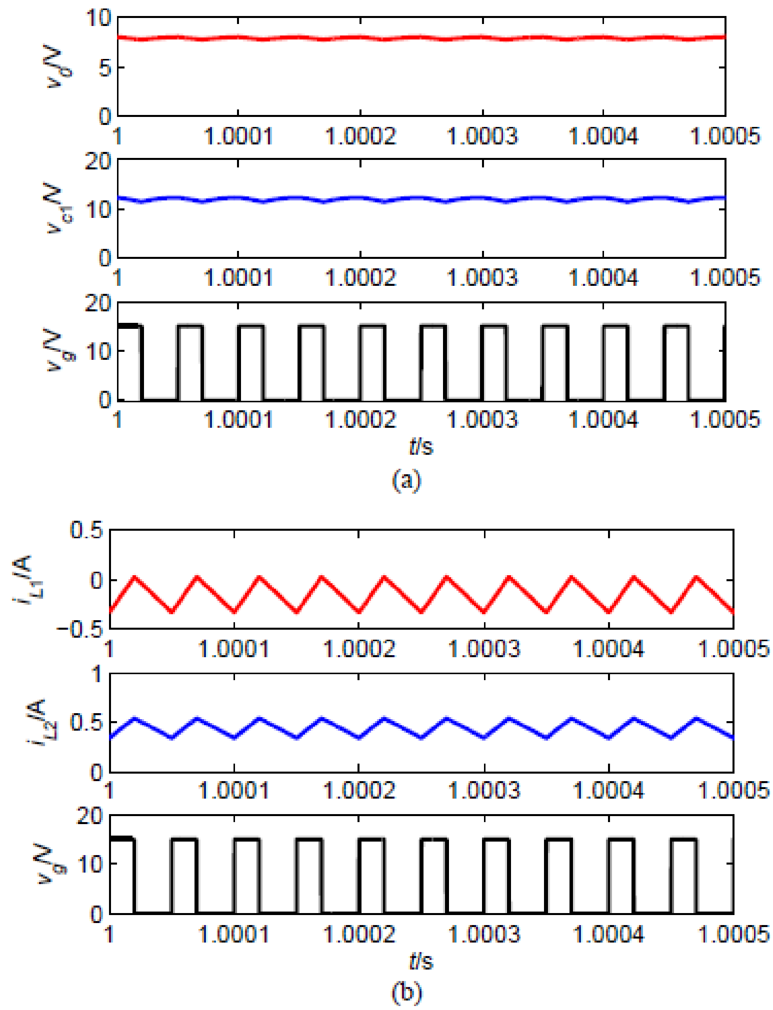

Fig. 6. PSIM simulations for the proposed buck-boost converter operating in step-down mode. (a) $v0$, $vC1$, and vg. (b) $iL1$, $iL2$, and vg.

From the above comparisons, one can see that the MATLAB simulations and the theoretical calculations are coinciding with each other, and they demonstrate the correctness of the theoretical analyses.

V. CONCLUSION

A new transformerless buck-boost converter, as a fourth-order circuit which realizes the optimization between the topology construction and the voltage gain to overcome the drawbacks of the traditional buck-boost converter, is proposed in this paper. The operating principles, steady-state analyses, and comparisons with other converters are presented. From the theoretical analyses, the MATLAB simulations and the circuit experiments, it is proved that the new transformerless buck-boost converter possesses the merits such as high step-up/step-down voltage gain, positive output voltage, simple construction and simple control strategy. Hence, the proposed buck-boost converter is suitable for the industrial applications requiring high step-up or step-down voltage gain.

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