International Journal for Modern Trends in Science and Technology
Volume: 03, Issue No: 05, May 2017
ISSN: 2455-3778
http://www.ijmtst.com

A New Transformerless Buck–Boost Converter with Positive Output Voltage

C.Susiladevi[1] | K.Venkatesan[2]

[1]PG Scholar, Department of EEE, Roever Engineering College, Perambalur, Tamilnadu, India.
[2]Assistant Professor, Department of EEE, Roever Engineering College, Perambalur, Tamilnadu, India.

To Cite this Article
C.Susiladevi and K.Venkatesan, “A New Transformerless Buck–Boost Converter with Positive Output Voltage”, *International Journal for Modern Trends in Science and Technology*, Vol. 03, Issue 05, May 2017, pp. 44-50.

ABSTRACT

A new transformerless buck–boost converterwith simple structure is proposed in this study. Comparedwith the traditional buck–boost converter, the proposedbuck–boost converter’s voltage gain is squared times of theformer’s and its output voltage polarity is positive. Theseadvantages enable it to work in a wider range of positiveoutput. The two power switches of the proposed buck–boost converter operate synchronously. In the continuousconduction mode (CCM), two inductors are magnetized andtwo capacitors are discharged during the switch-on period,while two inductors are demagnetized and two capacitorsare charged during the switch-off period. The power electronicssimulator (PSIM) and the circuit experiments are providedto validate the effectiveness of the proposed buck–boostconverter.

KEYWORDS: *Continuous conduction mode (CCM), newtransformerless buck–boost converter, positive outputvoltage.*

I. INTRODUCTION

AS is well known, switching-mode power supply is thecore of modern power conversion technology, which iswidely used in electric power, communication system, householdappliance, industrial device, railway, aviation, and manyother fields [1], [2]. As the basis of switching-mode powersupply, converter topologies attract a great deal of attentionand many converter topologies have been proposed. Buck converterand boost converter have the simple structure and highefficiency. However, due to the limited voltage gain, their applicationsare restricted when the low or high output voltage areneeded [3]. Luo converters can obtain high voltage gain byemploying 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 stepdownconversion ratio with low-voltage stress, while their operatingmode, converter structure, and control strategy are complicated[7]–[10]. Quadratic converters can achieve the voltagegain of cascade converters with fewer switches; however, theefficiency of these converters are low [11], [12]. Additionally,some switched networks are added into the basic converters toobtain the high-voltage step-up or step-down gain, at the priceof complicating construction and increasing cost [13]–[20].

Compared with the above-mentioned converter topologieswhich can only step-up or step-down voltage, the voltagebucking/boosting converters, which can regulate output voltageunder wider range of input voltage or load variations, are popularwith the applications such as portable electronic devices,car electronic devices, and so on.

The traditional buck–boostconverter with simple structure and high efficiency, as we allknown, has the drawbacks such as limited voltage gain, negativeoutput voltage, and floating power switch, meanwhilediscontinuous input and output currents. The other three basicnonisolated converters: 1) Cuk converter; 2) Sepic converter;and 3) Zeta converter, which also have the peculiarity of step-upand step-down voltage, have been provided. However, the limitsof the voltage gain along with other disadvantages in Cuk,Sepic, and Zeta converters are also nonignorable. The quadraticbuck–boost converter, proposed by Maksimovic and Cuk in, has one common-ground power switch; meanwhile, it canachieve the voltage gain $D2/(1 - D)2$. However, due to thediodes D1 and D2 clamp the output voltage to the input voltagewhile the duty cycle is bigger than 0.5, so that this convertercan only work in step-down mode.

By combining KY converterand the traditional synchronously rectified buck converter, Hwuand Peng proposed a new buck–boost converter whichcan 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 oftwo multiplies the duty cycle ($2D$) is not sufficiently high orlow in the situation where the converter needs to operate in awide range of output voltage. Moreover, based on the Cuk converter,a new buck–boost converter, which has the low outputvoltage ripple, minimal radio frequency interference, and onecommon-ground power switch. However, asa seventh-order circuit, the converter has complex construction,and both its input terminal and output terminal do not share thesame ground.

Besides, the voltage gain is still limited. In aboost–buck cascade converter, aggregating two separated converterswith current source and current sink, is applied for thethermoelectric generator. Nevertheless, the voltage gain of thiscascade converter is also constrained.

Especially, in order to obtain high-voltage step-up or stepdowngain, these converters must be operating under extremelyhigh or low duty cycle, and this point is too hard to realize dueto the practical constraints. Hence, exploring new topology ofbuck–boost converter to overcome the drawbacks of the conventionalones for satisfying the increasingly requirements inindustrial applications is very important and valuable.

In this study, by inserting an additional switched networkinto the traditional buck–boost converter, a new transformerlessbuck–boost converter is proposed. The main merit of the proposedbuck–boost converter is that its voltage gain is quadraticof the traditional buck–boost converter, so that it can operatein a wide range of output voltage, i.e., the proposed buck–boost converter can achieve high or low voltage gain withoutextreme duty cycle. Moreover, the output voltage of this newtransformerless buck–boost converter is common-ground withthe input voltage, and its polarity is positive.

This paper is organized as follows. In Section II, Existing system.Proposed system is provided in section III. Proposed converter structure is derived in section IV. Basic operating principles and analyses is derived in section V. Simulation verifications are shown in section VI. System descriptions are shown in section VII. Some concluding remarksand comments are given in Section VIII.

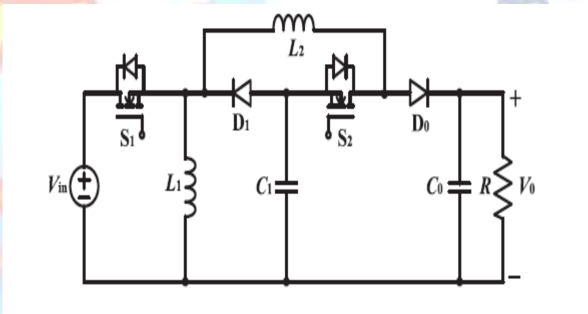

Fig. 1.Proposed transformerless buck–boost converter.

II. EXISTING SYSTEM

Normal Buck Boost converter operation. Buck converter and boost converter have the simple structure and high efficiency. However, due the limited voltage gain, their applications are restricted when the low or high output voltage are needed.To obtain high voltage gain voltage lift technique is required. It is more complex, also losses increase at the same time.

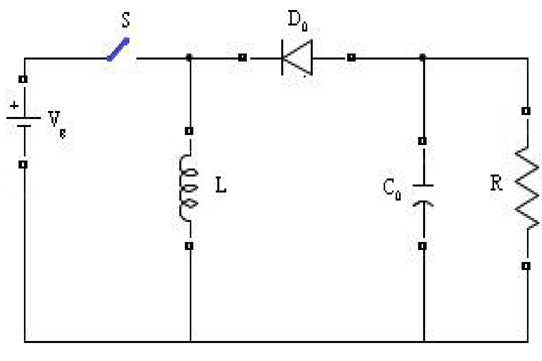

Fig. 2. Buck–boost converter

III. PROPOSED SYSTEM

Buck –Boost converter operating without transformer and it supplies high voltage gain. So it is used for wide range of positive output. In this proposed system Buck Boost converter's two switches are operating synchronously. In continuous conduction mode switch turn-on & turn-off periods are available.

A. Proposed block diagram

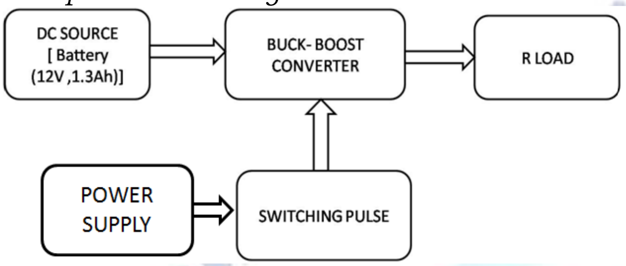

Fig. 3.Proposed Block Diagram

B. Proposed circuit diagram

In order to validate the effectiveness of the new transformerless buck–boost converter, we construct the prototype circuit as shown in Fig. 4.

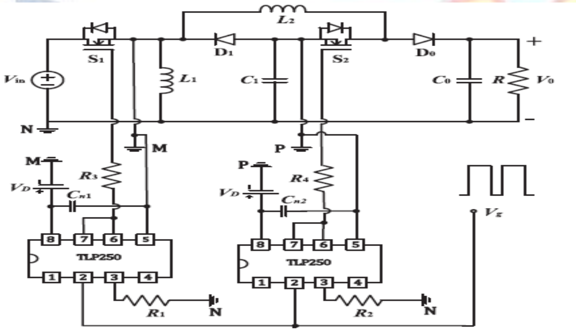

Fig. 4.Experimental circuit for the proposed buck–boost converter.

IV. PROPOSED CONVERTERSTRUCTURE

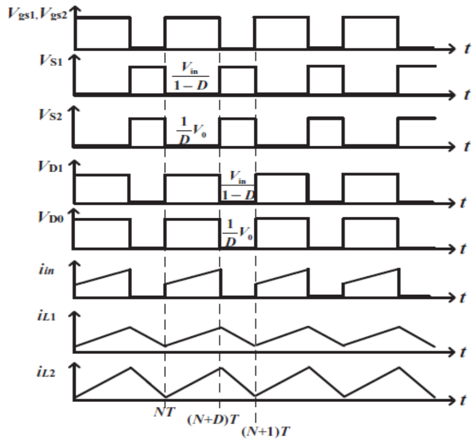

Fig. 5. Typical time-domain waveforms for the proposed buck–boost converter operating in CCM

Fig. 1 shows the circuit configuration of the new transformerlessbuck–boost converter, which consists of two powerswitches (S1 and S2), two diodes (D1 and D0), two inductors($L1$ and $L2$), two capacitors ($C1$ and $C0$), and one resistiveload R. Power switches S1 and S2 are controlled synchronously.

According to the state of the power switches and diodes, sometypical time-domain waveforms for this new transformerlessbuck–boost converter operating in CCM are displayed in Fig. 5,and the possible operation states for the proposed buck–boostconverter are shown in Fig. 6.

For Fig. 6(a), it denotes that thepower switches S1 and S2 are turned on, whereas the diodesD1 and D0 do not conduct. Consequently, both the inductor $L1$and the inductor $L2$ are magnetized, and both the charge pumpcapacitor $C1$ and the output capacitor $C0$ are discharged.

For Fig. 6(b), it describes that the power switches S1 and S2 areturned off while the diodes D1 and D0 conductfor its Forwardbiased voltage. Hence, both the inductor $L1$ and the inductor $L2$are demagnetized, and both the charge pump capacitor $C1$ andthe output capacitor $C0$ are charged.

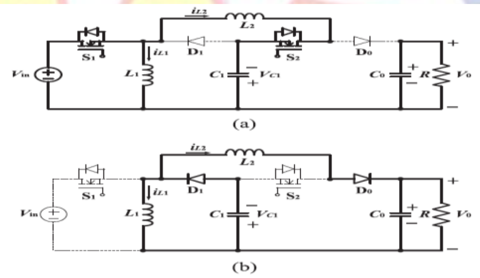

Fig. 6.Equivalent circuits of the proposed buck–boost converter in two possible states. (a) State 1. (b) State 2

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

V. BASIC OPERATING PRINCIPLES AND ANALYSES

A. Operating principles

As shown in Fig. 6, there are two states, i.e., state 1 andstate 2, in the new transformerless buck–boost converter whenit 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 arereverse biased. From Fig. 3(a), it is seen that $L1$ is magnetizedfrom the input voltage Vin while $L2$ is magnetized from theinput voltage Vin and the charge pump capacitor $C1$. Moreover,the output energy is supplied from theoutput capacitor $C0$.Thus, the corresponding equations can be established as

$$V_{L1} = V_{in} \quad (1)$$
$$V_{L2} = V_{in} + V_{C1}. \quad (2)$$

State 2:($(N + D)T < t < (N + 1)T$): During this time interval, the switches S_1 and S_2 are turned off, while D_1 and D_0 are forward biased. From Fig. 3.3(b), it is seen that the energy stored in the inductor L_1 is released to the charge pump capacitor C_1 via the diode D_1. At the same time, the energy stored in the inductor L_2 is released to the charge pump capacitor C_1, the output capacitor C_0, and the resistive load R via the diodes D_0 and D_1. The equations of the state 2 are described as follows:

$$V_{L1} = -V_{C1} \quad (3)$$
$$V_{L2} = -(V_{C1} + V_0). \quad (4)$$

If applying the voltage-second balance principle on the inductor L_1, then the voltage across the charge pump capacitor C_1 is readily obtained from (1) and (3) as

$$V_{C1} = (D / 1 - D)V_{in}. \quad (5)$$

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 L_2, the voltage gain of the proposed buck–boost converter can be obtained from (2), (4), and (5) as

$$M = V_0/V_{in} = (D/1 - D)^2. \quad (6)$$

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

B. Voltage stress

The voltage across the charge pump capacitor C_1 can be expressed as

$$V_{C1} = (D/ 1 - D)V_{in} = (1 - D/D)V_0. \quad (7)$$

Obviously, V_{C1} is less than the input voltage in step-down mode, and less than the output voltage in step-up mode. Consequently, the voltage stress on the charge pump capacitor C_1 is small so that we can choose the small-sized capacitor which have small parasitic resistor to reduce the power loss.

The voltage stress of the two power switches (S_1 and S_2) and two diodes (D_1 and D_0) can also be derived,

$$V_{S1} = (1/1 - D)V_{in} = (1 - D/D^2) V_0 \quad (8)$$
$$V_{S2} = (D/(1 - D)^2)V_{in} = (1/D)V_0 \quad (9)$$
$$V_{D1} = (1/1 - D)V_{in} = (1 - D/D^2)V_0 \quad (10)$$
$$V_{D0} = (D/(1 - D)^2)V_{in} = (1/D)V_0. \quad (11)$$

From (8) and (10), it can be seen that the voltage stress of the power switch S_1 and the diode D_1 are both equal to the voltage stress on the power switch in the traditional buck–boost converter with the same input voltage. Similarly, under the same output voltage condition, from (9) and (11),

It can be concluded that the voltage stress of the power switch S_2 and the diode D_0 are the same as the voltage stress on the diode in the traditional buck–boost converter.

C. Current stress

If the circuit loss is ignored, the input power and output power can be described as

$P_{in} = P_0$, namely,

$$V_{in} I_{in} = V_0 I_0. \quad (12)$$

Based on the voltage gain obtained in (6), the relationship between the dc input current and the dc output current is presented here,

$$I_0/I_{in} = (1 - D/D)^2. \quad (13)$$

The Ohm's law for the resistive load R is

$$V_0 = RI_0. \quad (14)$$

By using the ampere-second balance principle on the output capacitor C_0, we can show that the dc current I_{D0} through the diode D_0, equals I_0.

Accordingly, the relationship among the dc currents I_{L1}, I_{L2}, I_{in}, and I_0 can be depicted as follows:

$$I_{in} = D(I_{L1} + I_{L2}) \quad (15)$$
$$I_0 = (1 - D)\, I_{L2}. \quad (16)$$

From (6), (13)–(16), the following equations can be yielded:

$$I_{L1} = D^2(2D - 1)Vin/(1 - D)^4 R \quad (17)$$
$$I_{L2} = D^2\, Vin/(1 - D)^3 R. \quad (18)$$

We can get the conclusion from (17) that the negative inductor current of L_1 will appear in step-down mode, i.e., the duty cycle is smaller than 0.5.

The current stress of the two power switches (S_1 and S_2) and two diodes (D_1 and D_0) is

$I_{S1}= D(I_{L1}+ I_{L2}) = D^4\ Vin/(1 - D)^4R$ (19)
$I_{S2}= DI_{L2}=D^3\ Vin/(1 - D)^3R$ (20)
$I_{D1}= (1 - D)\ (I_{L1}+ I_{L2}) = D^3\ Vin/(1 - D)^3R$ (21)
$I_{D0}= (1 - D)I_{L2}=D^2Vin/(1 - D)^2R.$ (22)

From (19) to (22), it is found that the current stress of the power switch S2 and the diode D1 is both equal to the current stress on the power switch in the traditional buck–boost converterwith the same output current, and the current stress of the diode D0 equals to $I0$ is the same as the current stress on the diode in the traditional buck–boost converter, whereas the current stress on S1 in the proposed buck–boost converter is high.

D. Current Ripples Of Inductors

The ripples of the inductor current i_{L1} and i_{L2} can be given as

$\Delta i_{L1}=(V_{L1} / L_1)\ DT_S=DV_{in}/L_1f_s$ (23)

$\Delta i_{L2}=(V_{L2}/L_2)\ DT_S= DV_{in}/ (1 - D)L_2f_s$ (24)

wheref_s is the switching frequency. If the inductor current ripple, the input voltage V_{in}, the duty cycle D, and the switching frequency $f_s$are known, the inductance of L_1 and L_2 can be calculated from (23) and (24), so that the appropriate inductors can be selected in practical engineering.

E. Voltage Ripples Of Capacitors:

The ripples of the voltage across the capacitors C_1 and C_0,i.e., $\Delta_{\upsilon C1}$ and $\Delta_{\upsilon C0}$ are

$\Delta\upsilon_{C1} = (\Delta Q/C) = DVo / (1 - D)RC_1f_s$ (25)
$\Delta\upsilon_{C0}=(\Delta Q/C)= DV_0 / RC_0f_s.$ (26)

If the capacitor voltage ripples, the output voltage V_0, the duty cycle D, the resistive load R, and the switching frequency $f_s$are known, thecapacitance of C_1 and C_0 can be calculated based on (25) and (26).

F. Boundary Condition

For a converter operating in the boundary condition mode (BCM), the current of inductor just reduces to zero at the end of each switching cycle. Note that, here, we assume that the inductor current i_{L1} is continuous and only take the inductor L_2 as an example. The dc current of the inductor L_2 is,

$I_{L2} =((V_{in}+ V_{C1})/2L_2)DT_S.$ (27)

In addition, defining the normalized inductor time constant on the inductor L_2 as,

$\tau_{L2} =L_2f_s / R.$ (28)

From (5), (6), (14), (16), and (27), then, the boundary condition about the inductor L_2 can be derived as,

$\tau_{L2B} = (1 - D)^2 / 2D.$ (29)

It is clear from (28) and (29) that when $\tau_{L2} > \tau_{L2B}$, the proposed buck–boost converter operates in CCM. Otherwise, it operates in DCM.

G. Efficiency Analyses

To simplify calculating, the voltage and current ripples across the inductors and the capacitors are ignored. r_{DS1} and r_{DS2} are the MOSFET's (S_1 and S_2) ON-resistances.

V_{F1} and V_{F0} are the diodes' (D_1 and D_0) threshold voltage. r_{L1}, r_{L2}, r_{C1}, and r_{C0} are the equivalent series resistances of the inductors (L_1 and L_2) and the capacitors (C_1 and C_0), respectively.

The switches conduction losses can be calculated as follows:

$P_{SW(cond)} = I_{S1(rms)}{}^2r_{DS1}+ I_{S2(rms)}{}^2r_{DS2}$
$= (D^3P_{0}r_{DS1} / (1 - D)^4R) + (DP_{0}r_{DS2} / (1- D)^2R).$ (30)

The switches commutation losses are

$P_{SW(off)} =(1/2)I_{S1}V_{S1}t_{off1}f_s+(1/2)\ I_{S2}V_{S2}t_{off2}f_s$
$=(1/2)\ (D^2V_0 / (1 - D)^2R)\ ((1 - D)V_0/D^2)\ t_{off1}f_s + (1/2)(DV_0/(1 - D)R)\ (V_0/D)t_{off2}f_s.$ (31)

The diodes conduction losses can be derived as follows

$P_D= V_{F1}I_{D1}+ V_{F0}I_{D0}$
$= V_{F1}(D/1 - D)I_0+ V_{F0}I_0.$ (32)

The inductors losses are

$P_L= I_{L1(rms)}{}^2r_{L1}+ I_{L2(rms)}{}^2r_{L2}$
$= (2D - 1)^2P_0r_{L1}/ (1 - D)^4R + P_0r_{L2}\ (1 - D)^2R.$ (33)

The capacitors losses are

$P_C= I_{C1(rms)}{}^2r_{C1}+ I_{C0(rms)}{}^2r_{C0}$
$= DP_0r_{C1} / (1 - D)^3R + DP_0r_{C0} / (1 - D)R.$ (34)

Thus, the efficiency can be calculated as follows:

$\eta = P_0 / (P_0+ P_{SW(cond)} + P_{SW(off)} + P_D+ P_L+ P_C).$ (35)

From (30) to (34), the losses of the proposed buck–boost converter can be calculated. Based on calculated losses, the efficiency can be derived from (35).

VI. SIMULATION VERIFICATIONS

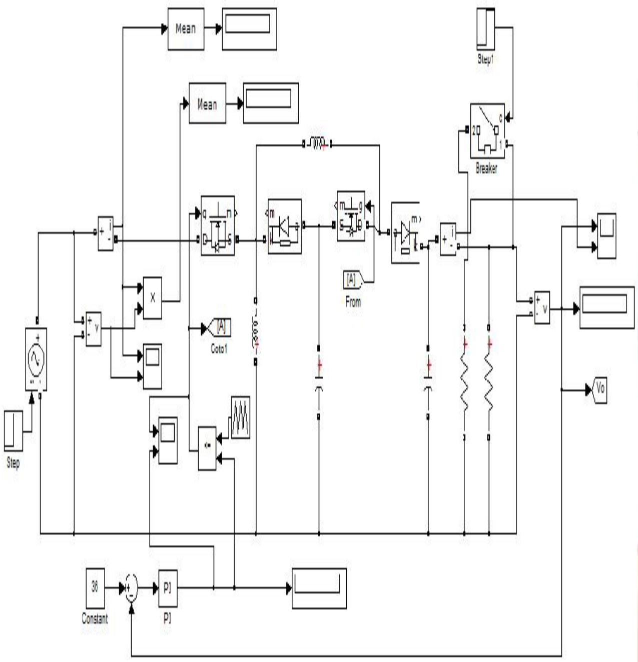

Fig. 7.Overall Circuit Model For transformer less Buck Boost Converter With Positive Output Voltage

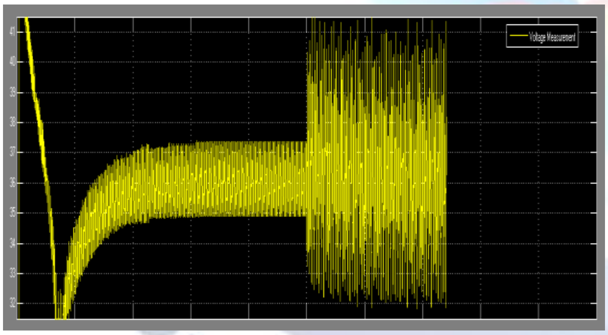

Fig. 8.Output voltage

VII. SYSTEM DESCRIPTION

Fig 9. Buck Boost Converter

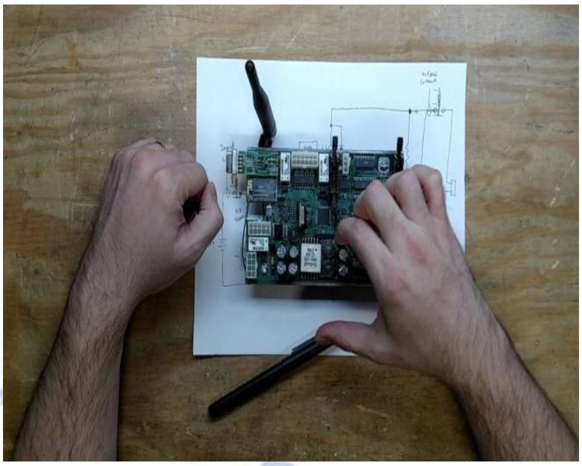

Fig 10.Transformerless buck boost converter

VIII. CONCLUSION

This paper has proposed a new transformerless buck–boostconverter as a fourth-order circuit, which realizes the optimizationbetween the topology construction and the voltage gainto overcome the drawbacks of the traditional buck–boost converter.The operating principles, steady-state analyses, smallsignal modeling, and comparisons with other converters arepresented.

From the theoretical analyses, the PSIM simulations,and the circuit experiments, it is proved that the newtransformerless buck–boost converter possesses the merits suchas 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 industrialapplications requiring high step-up or step-down voltage gain.

References

[1] W. H. Li and X. N. He, “Review of non-isolated high step-up DC/DCconverters in photovoltaic grid-connectedapplications,” IEEE Trans. Ind.Electron., vol. 58, no. 4, pp. 1239–1250, Apr. 2011.

[2] C. T. Pan and C. M. Lai, “A high-efficiency high step-up converter withlow switch voltage stress for fuel-cell system applications,” IEEE Trans.Ind. Electron., vol. 57, no. 6, pp. 1998–2006, Jun. 2010.

[3] T. F. Wu and Y. K. Chen, “Modeling PWM DC–DC converters outof basic converter units,” IEEE Trans. Power Electron., vol. 13, no. 5,pp. 870–881, Sep. 1998.

[4] F. L. Luo, “Six self-lift DC–DC converters, voltage lift technique,” IEEETrans. Ind. Electron., vol. 48, no. 6, pp. 1268–1272, Dec. 2001.

[5] F. L. Luo and H. Ye, “Positive output cascade boost converters,” Proc.Inst. Elect. Eng. Elect. Power Appl., vol. 151, no. 5, pp. 590–606, Sep.2004.

[6] Y. He and F. L. Luo, "Analysis of Luo converters with voltage-lift circuit,"Proc. Inst. Elect. Eng. Elect. Power Appl., vol. 152, no. 5, pp. 1239–1252,Sep. 2005.

[7] Y. T. Chen,W. C. Lin, and R. H. Liang, "An interleaved high step-up DC–DC converter with double boost paths," Int. J. Circ. Theor. Appl., vol. 43,no. 8, pp. 967–983, Aug. 2015.

[8] L.W. Zhou, B. X. Zhu, Q. M. Luo, and S. Chen, "Interleaved non-isolatedhigh step-up DC/DC converter based on the diode–capacitor multiplier,"IET Power *Electron.*, vol. 7, no. 2, pp. 390–397, Feb. 2014.

[9] C. T. Pan, C. F. Chuang, and C. C. Chu, "A novel transformerlessinterleaved high step-down conversion ratio DC–DC converter with lowswitch voltage stress," *IEEE Trans. Ind. Electron.*, vol. 61, no. 10,pp. 5290–5299, Oct. 2014.

[10] C. T. Pan, C. F. Chuang, and C. C. Chu, "A novel transformerlessadaptable voltage quadrupler DC converter with low switch voltagestress," *IEEE Trans. Power Electron.*, vol. 29, no. 9, pp. 4787–4796,Sep. 2014.

[11] J. A. Morales-Saldaña, R. Loera-Palomo, E. Palacios-Hernández, andJ. L. González-Martínez, "Modelling and control of a DC–DC quadraticboost converter with *R2P2* ," *IET Power Electron.*, vol. 7, no. 1, pp. 11–22, Jan. 2014.

[12] Y. M. Ye and K.W. E. Cheng, "Quadratic boost converter with low buffercapacitor stress," *IET Power Electron.*, vol. 7, no. 5, pp. 1162–1170, May2014.

[13] B. Axelrod, Y. Berkovich, and A. Ioinovici, "Switched-capacitor/switched-inductor structures for getting transformerless hybrid DC–DCPWM converters," *IEEE Trans. Circuits Syst. I, Reg. Papers*, vol. 55,no. 2, pp. 687–696, Mar. 2008.

[14] E. H. Ismail, M. A. Al-Saffar, A. J. Sabzali, and A. A. Fardoun, "A familyof single-switch PWM converters with high step-up conversion ratio,"*IEEE Trans. Circuits Syst. I, Reg. Papers*, vol. 55, no. 4, pp. 1159–1171,May 2008.

[15] M. Zhu and F. L. Luo, "Enhanced self-lift Cuk converter for negative-topositivevoltage conversion," *IEEE Trans. Power Electron.*, vol. 25, no. 9,pp. 2227–2233, Sep. 2010.

[16] K. I. Hwu and T. J. Peng, "A novel buck–boost converter combining KY and buck converters," *IEEE Trans. Power Electron.*, vol. 27, no. 5, pp. 2236–2241, May 2012.

[17] A. Ajami, H. Ardi, and A. Farakhor, "Design, analysis and implementation of a buck–boost DC/DC converter," *IET Power Electron.*, vol. 7, no. 12, pp. 2902–2913, Dec. 2014.

[18] R. Y. Kim and J. S. Lai, "Aggregated modeling and control of a boost-buck cascade converter for maximum power point tracking of a thermoelectric generator," in *Proc. 23rd IEEE Appl. Power Electron.Conf. Expo.*, Feb. 2008, pp. 1754–1760.

[19] R. D. Middlebrook and S. Cuk, "A general unified approach to modeling switching-converter power stages," *Int. J. Electron.*, vol. 42, no. 6, pp. 521–550, 1977.

[20] S. Onoda and A. Emadi, "PSIM-based modeling of automotive power systems: Conventional, electric, and hybrid electric vehicles," *IEEETrans. Veh. Technol.*, vol. 53, no. 2, pp. 390–400, Mar. 2004.