Published by :
http://www.ijert.org
International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 06, June - 2017

Transformerless Buck-Boost Converter with Positive Output Voltage and Feedback

Aleena Paul K
PG Student
Electrical and Electronics Engineering
Mar Athanasius College of Engineering
Kerala, India

Siny Paul
Associate Professor
Electrical and Electronics Engineering
Mar Athanasius College of Engineering
Kerala, India

Babu Paul
Professor
Electrical and Electronics Engineering
Mar Athanasius College of Engineering
Kerala, India

***Abstract*— A transformerless buck-boost converter with simple structure is obtained by inserting an additional switched network into the traditional buck-boost converter. Compared with the traditional buck-boost converter, its voltage gain is quadratic of the traditional buck-boost converter. 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 transformerless buck-boost converter is common-ground with the input voltage, and its polarity is positive. The two power switches of the buck-boost converter operate synchronously. The operating principles of the buck-boost converter operating in continuous conduction modes are presented. A new buck-boost converter is presented by providing a feedback to the converter. By this, constant output voltage can be maintained under varying load conditions in both buck and boost operation. The PSIM(POWER SIM) simulations are provided to compare and validate the effectiveness of the buck-boost converters. A prototypecircuit is constructed. Microprocessor dsPIC30f2010 is used to generate the control pulses.**

Keywords*— BLDC (Brushless DC), Discontinuous Inductor Current Mode (DCM), Voltage Source Inverter (VSI)

I. INTRODUCTION

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. 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. 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 know, has the drawbacks such as limited voltage gain, negative output voltage, oating power switch, meanwhile dis-continuous 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 nonignorable.

Typical PWM DC-DC converters include the well-known buck, boost, buck-boost, Cuk, Zeta, and Sepic. With proper reconfiguration, these converters can be represented in terms of either buck or boost converter and linear devices, thus, the buck and boost converters are named BCUs[2]. The PWM converters are, consequently, categorized into buck and boost families. With this categorization, the small signal models of these converters are readily derived in terms of h parameter (for buck family) and g parameter (for boost family).Using the proposed approach, not only can one find a general configuration for converters in a family, but one can yield the same small-signal models as those derived from the direct state-space averaging method. Additionally, modeling of quasi-resonant converters and multi resonant converters can be simplified by adopting this approach[2].

Interleaved non-isolated high step-up DC/DC converter consists of two basic boost cells and some diode-capacitor multiplier (DCM) cells as needed. Because of the DCM cells, the voltage conversion ratio is enlarged and the extreme large duty ratio can be avoided in the high step-up applications. Moreover, the voltage stress of all the power devices is greatly lower than the output voltage. As a result, lower-voltage-rated power devices can be employed, and higher efficiency can be expected. Since the two basic Boost cells are controlled by the interleaving method, which means the phase difference between the two pulse width modulation (PWM) signals is 180° and the input current is the sums of the two inductor currents, the input current ripple is decreased and the size of the input filter could be reduced, which make it a suitable choice in the photovoltaic power generation system and hybrid electric vehicles, etc. But their operating mode, converter structure and control strategy are complicated[4].

The transformerless buck-boost converter is obtained by inserting an additional switched network into the traditional buck-boost converter. 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[1].

This paper proposes a new transformerless buck boost converter with a feedback to obtain constant output voltage regardless of varying load conditions. And it works with simple operating modes. The complete system is simulated in PSIM and hardware section of the converter is done.

I. TRANSFORMERLESS BUCK-BOOST CONVERTER WITH POSITIVE OUTPUT VOLTAGE AND FEEDBACK

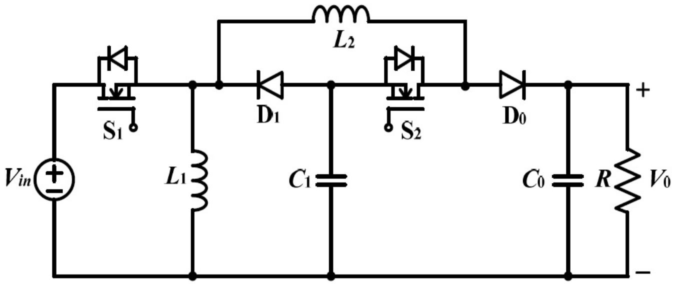


Fig-1: Proposed converter

A new transformerless buck-boost converter is obtained by inserting an additional switched network into the traditional buck-boost converter. 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.

a) Converter Structure

The circuit configuration of the new transformerless buck-boost converter is shown in fig-1. It consists of two power switches (S_1 and S_2), two diodes (D_1 and D_O), two inductors (L_1 and L_2), two capacitors (C_1 and C_o), and one resistive load R. Power switches S_1 and S_2 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 figures 3 and 4. Figure 3, it denotes that the power switches S_1 and S_2 are turned on whereas the diodes D_1 and D_O 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_O are discharged. Figure 4, it describes that the power switches S_1 and S_2 are turned off while the diodes D_1 and D_O 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_O are charged.

b)Operating Principles

As shown in fig-2, there are two modes, that is, mode 1 and mode 2, in the new transformerless buck-boost converter when it operates in CCM operation. Mode 1 between time interval (NT<t<(N+D)T). Mode 2 between time interval ((N+D)T<t<(N+1)T).

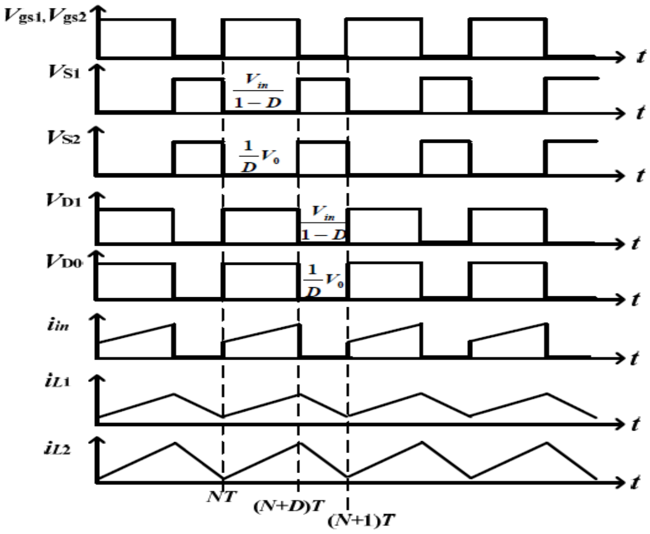


Fig-2: Typical Time-Domain Waveforms for the Buck-Boost Converter Operating in CCM.

- *Mode 1(NT<t<(N+D)T)*
  Mode 1 is during the time interval (NT<t<(N+D)T). During this time interval, the switches S_1 and S_2 are turned on, while D_1 and D_O are reverse biased. From fig-3, it is seen that L_1 is magnetized from the input voltage Vin while L_2 is magnetized from the input voltage V_{in} and the charge pump capacitor C_1. Also, the output energy is supplied from the output capacitor C_O. Thus, the corresponding equations can be established as,

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

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

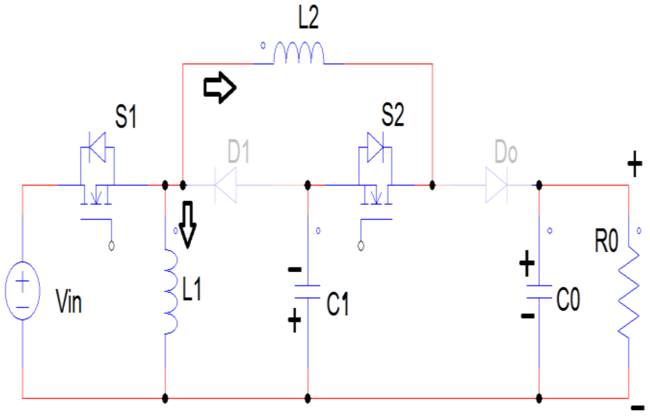


Fig-3: Equivalent circuit of the buck-boost converter in mode 1

- *Mode 2*[$t_1 - t_3$] $((N+D)T<t<(N+1)T)$

  State 2 is during the time interval ((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_O are forward biased. From fig- 4, 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_O and the resistive load R via the diodes D_O and D_1. The equations of the state 2 are described as follows

$$V_{L1}= -V_{C1}\text{...}(3)$$

$$V_{L2}= -(V_{C1}+V_O)\text{..}(4)$$

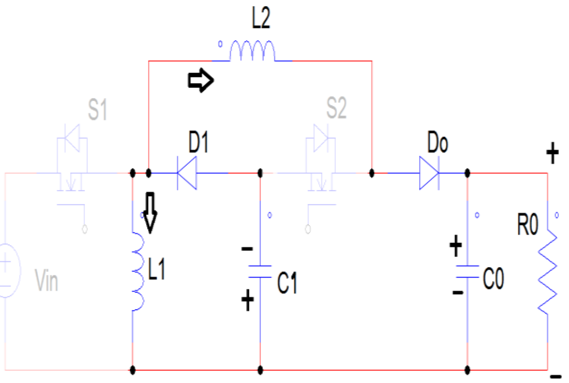


Fig-4: Equivalent circuits of the buck-boost converter in mode 2.

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 equations (1) and (3) as

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

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 equations (2), (4), and (5) as

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

From equation (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.

II. SIMULATION MODEL AND RESULTS

The circuit of the new transformerless buck-boost converter is simulated using the PSIM software to confirm the aforementioned analyses. Circuit parameters chosen are shown in the table.

Table-1: Simulation Parameter

Parameter	Value
V_{in}	18V
f_s	20kHz
D	0.4 - 0.6
L_1	1mH
L_2	3mH
C_1	10µF
C_2	20µF

a) *Simulation Model*

Fig-5 shows the image of simulation circuit of the new transformerless buck-boost converter. It consists of two power switches (S_1 and S_2), two diodes (D_1 and D_o), two inductors (L_1 and L_2), two capacitors (C_1 and C_o), and one resistive load R. Power switches S_1 and S_2 are controlled synchronously.

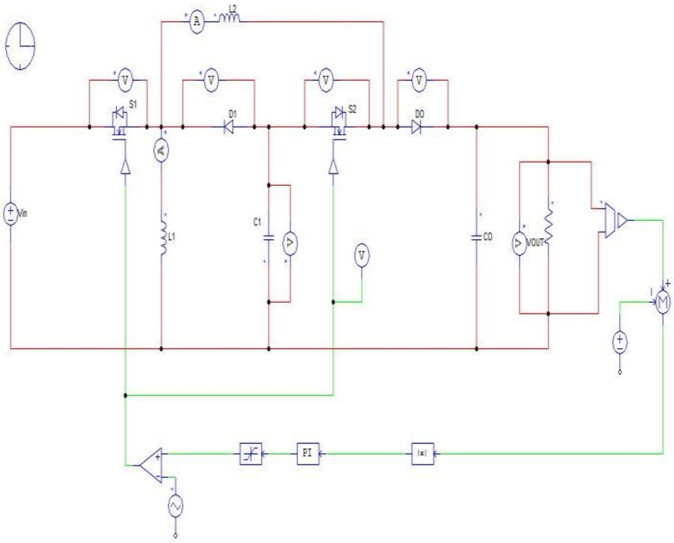


Fig-5: PSIM Model of Transformerless Buck-Boost Converter with Feedback

b) *Simulation Results*

Fig-6 shows the time-domain waveforms of the output voltage V_{OUT}, the charge pump capacitor voltage V_{C1} and the driving signal V_{SIG}.

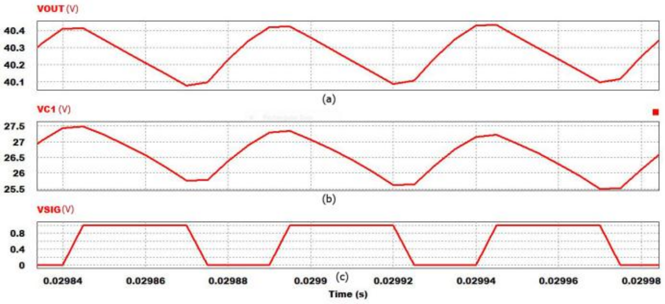


Fig-6: PSIM simulations for the buck-boost converter operating in step-up mode

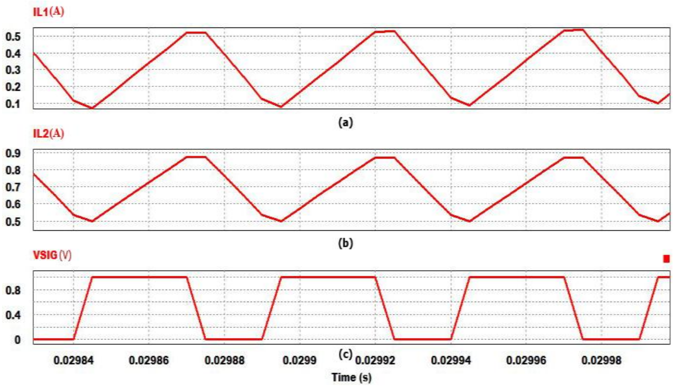


Fig-7: PSIM simulations for the buck-boost converter operating in step-up mode

Fig-7 shows the currents of the two inductors L_1 and L_2, and the driving signal V_{SIG} 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 V_{SIG} is chose. From fig-7, one can obtain that the charge pump capacitor voltage V_{C1} is within (25.8V, 27.5V), the output voltage V_O is within (40.4V, 40.1V), the inductor current I_{L1} is within (0.07A, 0.3A), and the inductor current I_{L2} is within (0.36A, 0.52A). Also, the ripples of the inductor current ΔI_{L1} and the inductor current ΔI_{L2} are 0.23A and 0.16A, respectively. Additionally, the ripples of the two capacitors ΔV_{C1} and ΔV_{CO} are 1.7V and 0.3V, respectively.

From the design equations[1] the theoretical results are V_{C1}=27V, V_{OUT} =40.5V, I_{L1}=0.34A, I_{L2}=0.68A, ΔI_{L1}=0.54A, ΔI_{L2}=0.45A, ΔV_{C1}=2V, ΔV_{CO}=0.4V, respectively.

For the proposed buck-boost converter operating in step-down mode when the duty cycle is choosing as 0.4. Fig-8 displays the time-domain waveforms of the output voltage V_{OUT} , the charge pump capacitor voltage V_{C1} and the driving signal V_{SIG}
Fig-9 shows the currents of the two inductors L_1 and L_2, and the driving signal V_{SIG}. It is clearly seen that the charge pump capacitor voltage V_{C1}, the output voltage V_{OUT}, the inductor current I_{L1}, and the inductor current I_{L2} are within (11.6V,12.32V), (7.77V, 8.00V), (-0.27A, 0.03A) and(0.36A, 0.52A), respectively. Also, the ripples of the inductor current $4I_{L1}$ and the inductor current $4I_{L2}$ are 0.3A and 0.16A, respectively. And, the ripples of the two capacitors ΔV_{C1} and ΔV_{CO} are 0.72V and 0.23V, respectively. Similarly, the theoretical calculations from the design equations are V_{C1}=12V, V_{OUT}=8V, I_{L1}=-0.15A, I_{L2}=0.44A, ΔI_{L1}=0.36A, ΔI_{L2}=0.2A, ΔV_{C1}=0.89V, ΔV_{CO}=0.27V, separately.

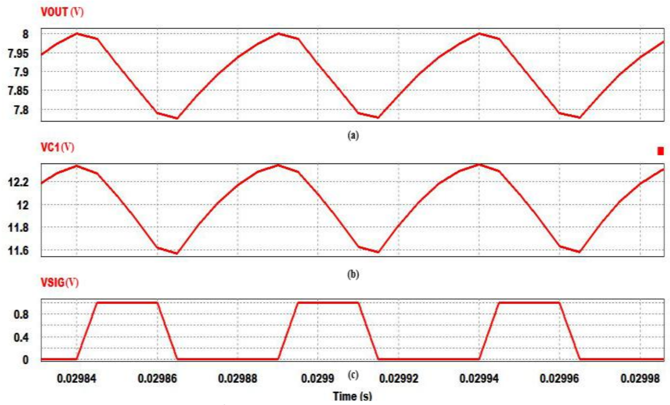


Fig-8: PSIM simulations for the buck-boost converter operating in step-down mode

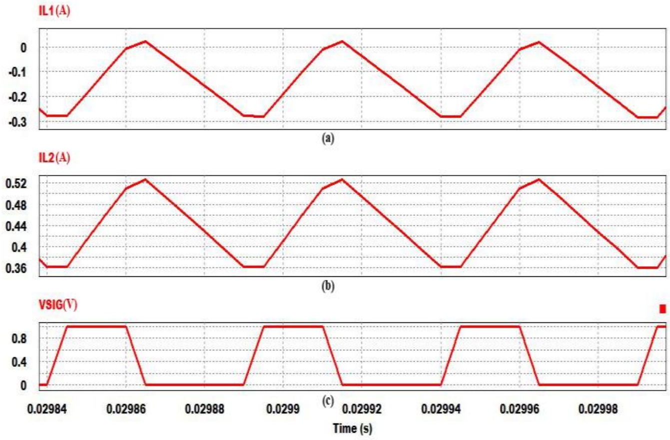


Fig-9: PSIM simulations for the buck-boost converter operating in step-down mode

Table-2: Comparison between the converters

	Transformerless Buck-Boost Converter	Transformerless Buck-Boost Converter with Feedback
No. of switches	2	2
No. of diodes	2	2
No. of inductors	2	2
No. of capacitors	2	2
Output voltage ripple (Buck mode)	±0.135V	±0.115V
Output voltage ripple (Boost mode)	±0.2V	±0.15V

Table 2 shows the comparison between the two converters, transformerless buck-boost converter[1] and transformerless buck-boost converter with feedback, output voltage ripple is decreased by 55 percentage in the boost mode and 14.8 percentage in the buck mode.

III. EXPERIMENT SETUP AND RESULTS

Hardware setup is done in a Printed Circuit Board (PCB). Control circuit and power circuit are implemented in two PCBs. Here dsPIC30F2010 is used for generating a pulse of constant switching frequency and duty ratios. The components list for the hardware is given in table 3.

Table-3: Prototype Components

Components	Specification
Input Voltage	12V
Output Voltage	40V/8V
Switching Frequency	20kHz
Diode	Byq28e200e
MOSFET	IRF840
Inductors(L_1 & L_2)	1mH & 3mH
Capacitor(C_1)	10μF
Output Capacitor(C_O)	20μF
Controller	dsPIC30F2010
Driver IC	TLP250

Hardware setup is done i.e the converter section. Experimental setup is shown in fig-10.Sections in the hardware is rounded and marked separately.

a) Converter without feedback

Pulse for buck operation is shown in fig-11(a). Pulse for boost operation is shown in fig-11(b). The frequency is 20kHz.

The output voltage of the transformerless buck boost converter varies with changing load. The load is varied using rheostat. Load change from 20 to 40 ohm is provided in the buck mode. The voltage varies from 6.45V to 7.5V. The output voltage of the converter in buck operation is shown in fig-12. Figure 12(a),(b),(c) respectively shows the output voltage for load 30Ω,20Ω and 40Ω.

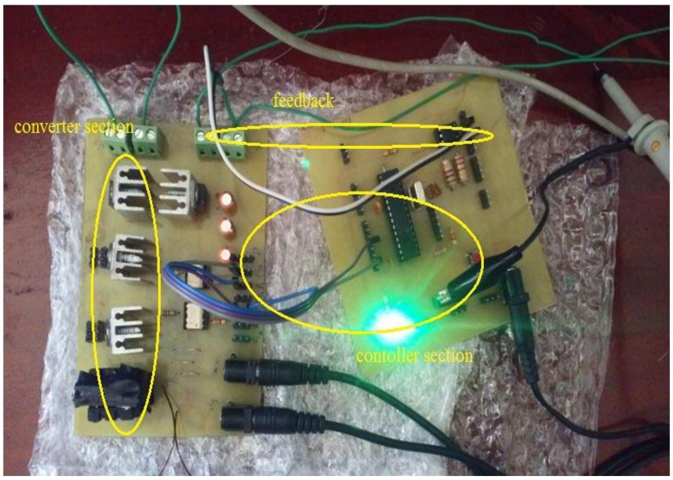


Fig -10: Experimental set up

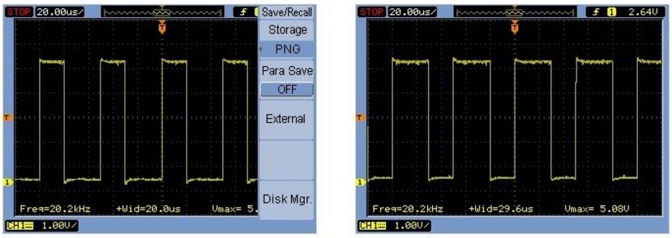
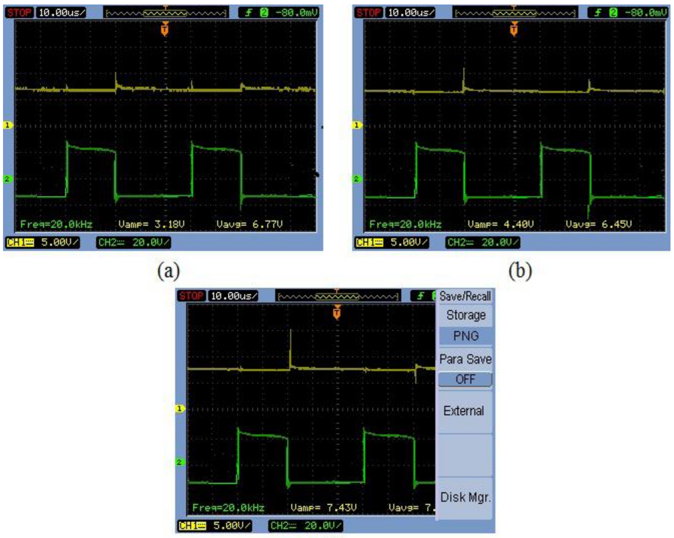


Fig -11: (a)Pulse for buck operation D=0.4(b)Pulse for boost operation D=0.6

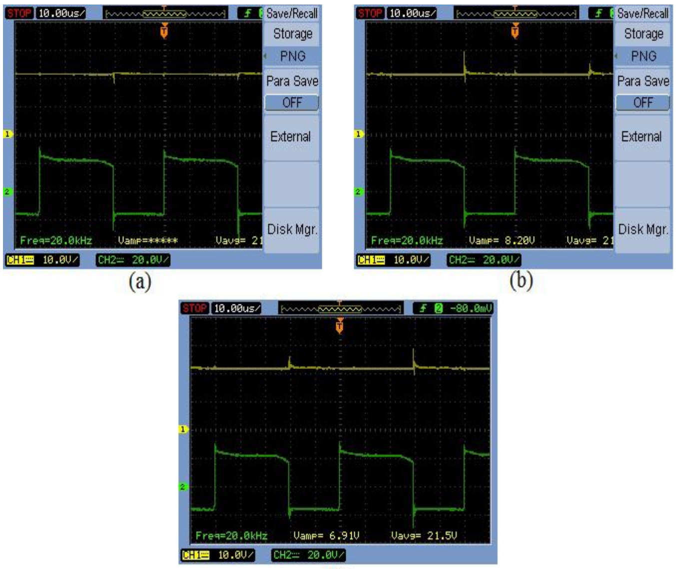


(a) (b)

(c)

Fig -12: Output Voltage varying with load -buck operation

The output voltage of the converter in boost operation is shown in fig-13. Load change from 120Ω to 180Ω ohm is provided in the boost mode. And the voltage varies from 21V to 21.5V.Figure 13(a),(b),(c) respectively shows the output voltage for load 150Ω, 120Ω and 180Ω.



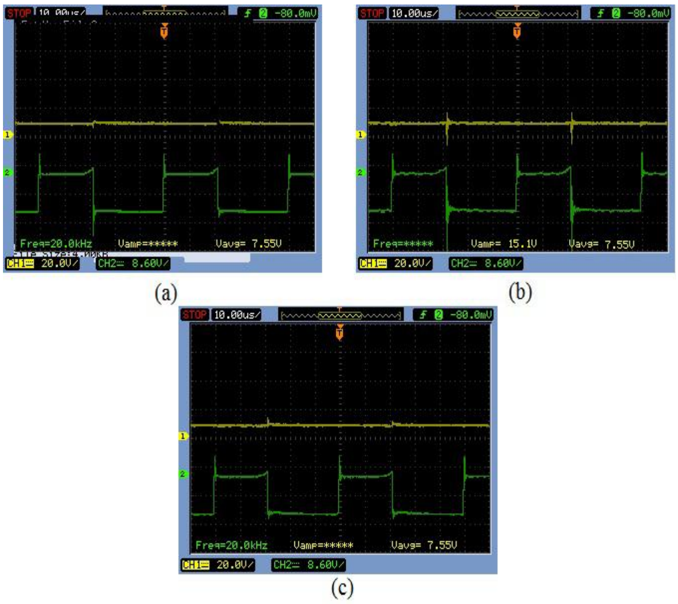
(a) (b)

(c)

Fig -13: Output Voltage varying with load -boost operation

b) Converter with feedback

A feedback is provided to the transformerless buck boost converter. So that the output voltage remains constant irrespective of load conditions. Rheostat is provided as the load.

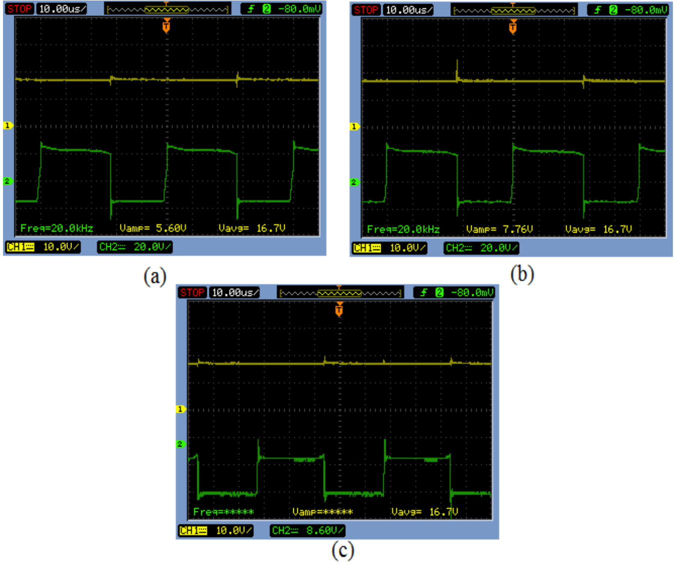


(a) (b) (c)

Fig -14: Output Voltage constant -buck operation

Output voltage for the buck operation is shown in fig- 14. Figure 14(a),(b),(c) respectively shows the output voltage for load 30Ω, 20Ω and 40Ω. From the figure it is clear that the output voltage is constant irrespective of the load change. Output voltage is 7.55V

Output voltage for the boost operation is shown in fig-15. Figure 15(a),(b),(c) respectively shows the output voltage for load 150 Ω,120 Ω and 180 Ω. From the figure it is clear that the output voltage is constant irrespective of the load change. The output voltage is 16.7V



(a) (b) (c)

Fig -15: Output Voltage constant -boost operation

IV. CONCLUSION

Transformerless buck-boost converter is simulated using PSIM and analyzed. It is obtained by inserting an additional switched network into the traditional buck-boost converter. Transformerless buck-boost converter possesses the merits such as high step-up and 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. The converter operate in a wide range of output voltage without using extreme duty cycles. It provides enough gain within the duty ratio 0.4-0.6. It has simple operating modes. In order to make the output voltage constant irrespective of load conditions a feedback is provided.

REFERENCE

[1] Shan Miao and Faqiang Wang, "A New Transformerless Buck-Boost Converter with Positive Output Voltage" , IEEE Trans. Industrial Electronics, vol.30, no.4, Feb 2016.

[2] T. F. Wu, and Y. K. Chen, "Modeling PWM DC-DC converters out of basic converter units ", 2008 IEEE Trans. Power Electron.", vol. 13, no. 5, pp.870-881, Sep 1998.

[3] F. L. Luo, and H. Ye, "Positive output cascade boost converters ", IEE Proc. Electr. Power Appl., vol. 151, no. 5, pp.590-606, Sep 2004.

[4] C. T. Pan, C. F. Chuang, and C. C. Chu , "A novel transformerless interleaved high step-down conversion ratio DCDC converter with low switch voltage stress" , IEEE Trans. Ind Electron. , vol. 61, no. 10, pp. 5290-5299, Oct 2014.

[5] D. Maksimovic, and S. Cuk, "Switching converters with wide DC conversion range , IEEE Transactions on Industry Applications", vol. 6, no. 1, pp.2236-2241, May. 2012.

[6] 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.

[7] 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.

[8] 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", Appl. Power Electron. Conf. Expos, pp.1754-1760, Feb. 2008.

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