A Novel DC-DC Boost Converter Based on Voltage-Lift Technique

Nihala K Shereef[1], Neena Mani [2], Neetha John [3]
[1]*Post Graduate Student, Department of EEE, Mar Athanasius College of Engineering, Kothamangalam , Kerala India*
[2,3]*Assistant Professor, Department of EEE, Mar Athanasius College of Engineering, Kothamangalam , Kerala India*

Abstract—Nowadays, DC-DC converters are widely used. These types of power electronic converters are controlled using pulse width modulation (PWM) and switching frequency. Different topologies of converters are introduced to improve the efficiency. Here a new structure of non-isolated boost DC-DC converters based on voltage-lift (VL) technique is explained. This converter is designed with less number of components. In comparison with conventional non-isolated boost DC-DC converters, the defined converter generates higher voltage gain. The voltage and current waveforms of all elements in continuous conduction mode (CCM) are observed. Then, the critical inductance and stress of switch current are extracted. Switching pulse is generated using PIC16F877A. The validity of all the theories is examined experimentally. The prototype of the hardware is implemented and output voltage of 35V is observed with an input voltage of 5V.
Keywords— DC-DC Converter, Continuous Conduction, Critical inductance, Voltage Lift

I. INTRODUCTION

The requirement for High voltage dc power supplies has become necessary in renewable energy systems, in electric vehicles, X-rays systems etc. But this could not be met with conventional DC-DC converters because they require high duty ratio operation, sometimes transformer for stepping up the voltage and also they do not support high switching frequencies. To reduce the size of the dc-dc converter, one of the solutions is to operate the converter at high switching frequency so that this results in the small size of the inductor and capacitors. The converters that switching is controlled by PWM technique are classified into two isolated and non-isolated groups. In the structure of non-isolated DC-DC converters such as buck, boost, buck-boost, CUK, and SEPIC converters, there is no high frequency transformer and as a result, non-isolated DC-DC converters have lower price, smaller size and lower switching losses and high efficiency.

Among non-isolated DC-DC converters, the conventional non-isolated boost converter due to high voltage gain, direct connection of inductor at input, and lower input capacitance at output and smaller filter size, switch protection against over voltage and electromagnetic interference(EMI), lower power stress on the elements, higher transient response ratio, higher efficiency and power density has many applications in LED lighting systems, auxiliary equipment of hybrid cars and green energy systems such as fuel cell systems, PV systems and WT systems.

In these applications, the non-isolated boost converter acts as an interface between low-voltage sources and high voltage load and plays an important role in increasing the output voltage gain from low voltage. Assuming that the converter is ideal in theory, and is in CCM, very high voltage gain would be achieved of a conventional non-isolated boost converter for high duty cycle ratio. However, due to substantial switching and conduction losses of the diodes and decrease in efficiency with increase of the voltage gain, especially in high loads, restoring the problem in the high voltage EMI of elements and high voltage stress of switching, rate of duty cycle is about 0.8 and voltage gain is almost limited to four times. Therefore, the use of conventional non-isolated boost converters in high voltages would not be appropriate. To overcome these problems and improve the profile of these converters many methods and techniques have been presented in recent years. Here, a new structure for non-isolated boost DC-DC converter based on VL technique is presented that has higher voltage gain. In the followings, equations for elements of the non-isolated boost DC-DC converter in CCM and DCM are extracted, and the voltage gain and critical inductance between CCM and DCM for DC-DC converters are calculated. Then, the current stress of switch in CCM and DCM is evaluated

II. A NOVEL DC-DC BOOST CONVERTER BASED ON VOLTAGE-LIFT TECHNIQUE

Voltage Lift Technique is a popular and effective technique for increasing the output voltage gain that has been used extensively in the power electronics circuits. Using this technique, characteristics of conventional non-isolated boost DC-DC converters are well improved. Using this method, the input voltage increases step to step to transfer high voltage gain to load. The performance of VL technique is based on energy storage elements (inductor and capacitor). High power density, high efficiency, simple structure and cheapness compared to other techniques and small output

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voltage ripple, especially for high voltage values are the features of this technique. In addition, the lack of additional switches that lead to the complexity of the control system of a dc-dc converter is an important feature of this technique.
The structure of the converter is shown in Figure 3.1. According to Figure 3.1, the structure of the converter consists of one power switch, two inductors, three capacitors and three diodes. For the convenience of analysis, the following assumptions are made: (a) The converter is analyzed in the steady state, (b) The output voltage is constant, (c) The capacitors are large enough, so, the voltage of capacitors is assumed to be constant in each switching cycle, d) The switch and diodes are ideal. The volt- age and current relations of each element in continuous conduction mode(CCM)and discontinuous conduction mode(DCM) are determined in the following.

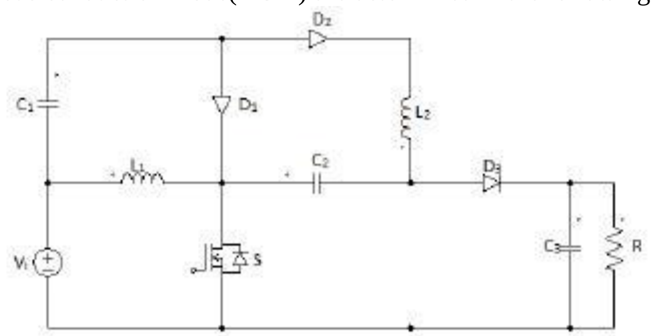


Fig. I: Voltage lift technique based DC-DC converter proposed in [1].

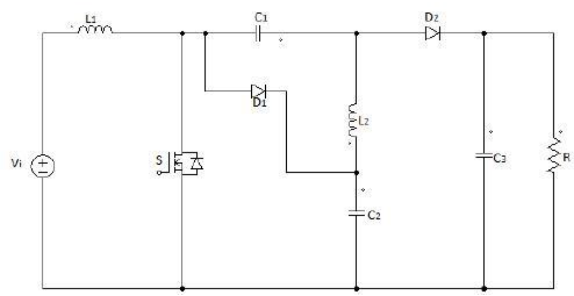


Fig. II: Proposed voltage lift technique based DC-DC boost converter

III. OPERATING PRINCIPLE

Equivalent circuits and the key waveforms of the converter under continuous conduction mode (CCM) is explained in the following section. The CCM consists of two operating mode including Ton and Toff. The operating modes are discussed in detail as follows.

3.1. Mode I

In this mode of operation the switch is turned on diodes D1 and D2 are reverse biased. Current flows through both the inductors. Capacitor C1 is charging and C2, C3 are discharging in nature.

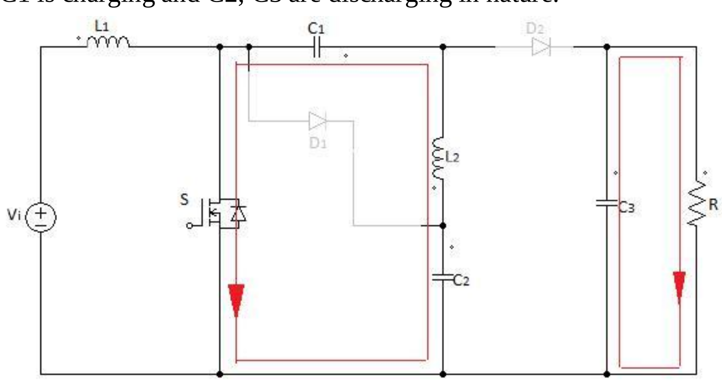


Fig. III: Operating circuit of mode I

3.2. Mode II

In this mode of operation the switch is turned on. Diodes D1 and D2 are forward biased. Current flows through both the inductors. Capacitor C1 is discharging and C2, C3 are charging in nature.

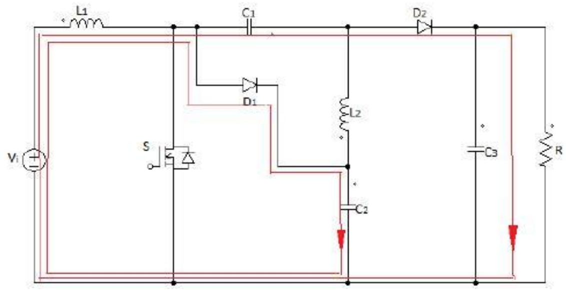


Fig. IV: Operating circuit of mode II

IV. COMPARISON OF DIFFERENT BOOST CONVERTERS

Table I Comparison of different boost converters

	Conventional boost converter	VL technique based converter	Modified VL based converter
No. of diodes	1	3	2
No. Of inductors	1	2	2
No. Of capacitors	1	3	3
Output voltage	24V	36V	35V
Voltage gain	2	3	2.9
Voltage stress across MOSFET	12V	24V	22V
Voltage ripple	0.12V	0.025V	0.035V
Efficiency	76%	94%	92%

From the above comparison it is evident that the modified converter gives better performance than other converters.

V. DESIGN OF COMPONENTS

In this converter an input voltage of 12V is used and switching frequency is 10 kHz. Load resistance is assumed to be 100 ohm. Duty ratio of 50 % is chosen.

5.1. Inductor Design

(5.1) $$L_{C1} \geq \frac{1}{2}\left(\frac{D*(1-D)^3}{1+D} + \frac{R*D}{f}\right)\frac{1}{f}$$

$$L_{C2} \geq \frac{1}{2}\left(\frac{D*(1-D)^3}{1+D} + \frac{R*D}{f}\right)\left(\frac{D^2}{1-D} + \frac{1+D}{1-D}\right)\frac{R}{f}$$

(5.2)

5.2. Capacitor Design

(5.3) $$C \geq \frac{I_O * D}{4 * f * \Delta V_C}$$

VI. SIMULATION PARAMETERS

Table II Simulation parameters

System parameters	Specifications
Duty cycle	50%
Switching frequency	10KHz

Input voltage	12V
Inductor L_1,L_2	1.2Mh
Capacitor C_1, C_2 Capacitor C_3	110µF 63µF
Load resistance	100Ω

VII. SIMULATION MODEL AND RESULT

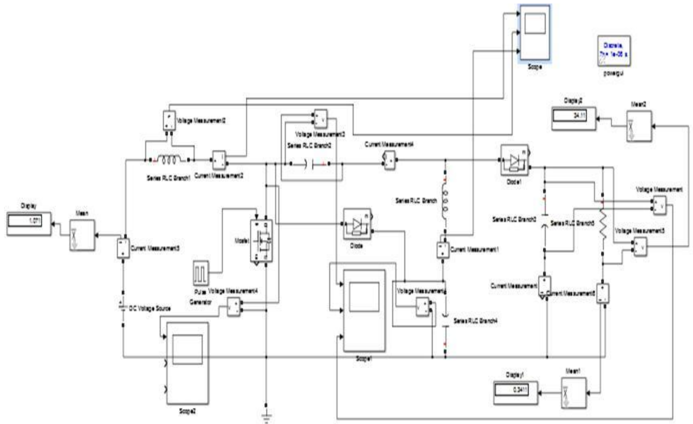


Fig. V: Simulation model of the proposed converter

A model of the modified converter is set up and the following waveforms are obtained in Simulink.
Fig.VI shows gate pulse given to switch and voltage stress across switch. Stress across switch is around two third of the output voltage.

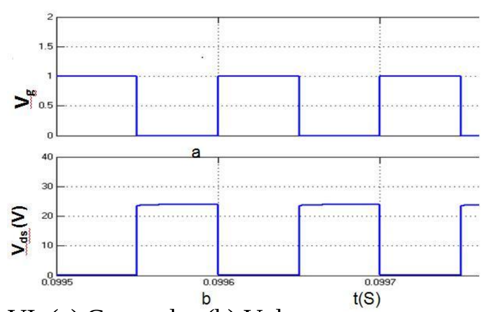


Fig. VI: (a) Gate pulse (b) Voltage stress across switch

Fig.VII shows the current waveforms in continuous conduction mode. Current through inductors never become zero and thus the continuous mode of operation.

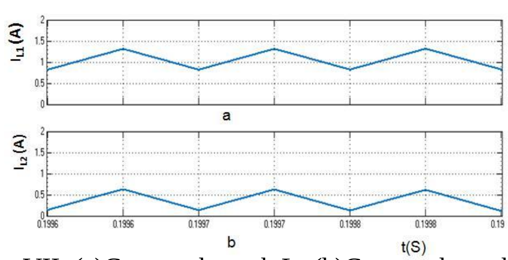


Fig. VII: (a)Current through L_1 (b)Current through L_2

Fig.VIII shows the voltage across C3 which is the output voltage itself.

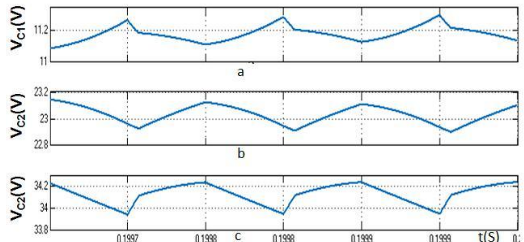


Fig. VIII: (a)Voltage across C_1 (b)Voltage across C_2 (c)Voltage across C_3

Fig.IX shows the input voltage and output voltage in continuous conduction mode. For an input voltage of 12V, an output voltage of 33.3V is obtained.

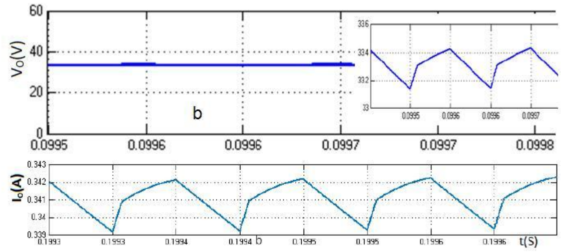
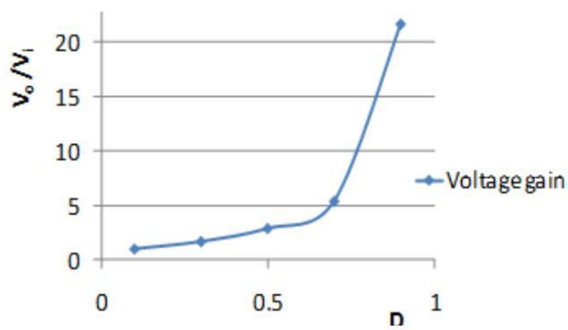
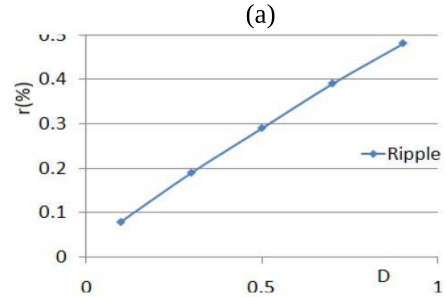


Fig. IX: (a) Output voltage (b) Output current

VIII. ANALYSIS OF THE CONVERTER



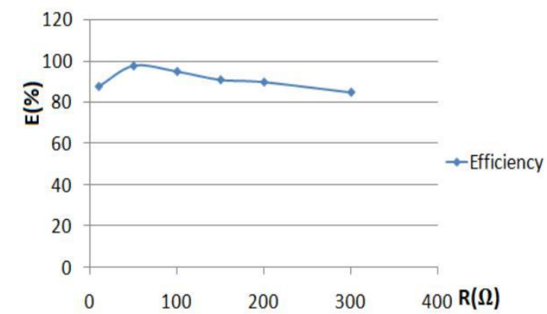
(a)



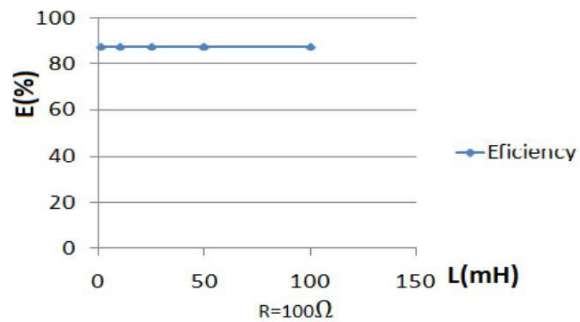
(b)

Fig.X: (a) Voltage gain Vs Duty ratio (b) Voltage ripple Vs duty ratio

The voltage gain and the ripple in output voltage increases with the duty ratio. Above 0.5 duty ratio the voltage ripple increases beyond the limit.



(a)



(b)

Fig. X: (a) Efficiency Vs R Load (b) Efficiency Vs RL Load

The efficiency of the converter is higher with resistive load. Efficiency increases initially and then tends to decrease. Thus a load resistance of 100Ω is used for optimum efficiency. The efficiency with RL load remains almost constant with varying inductance.

IX. EXPERIMENTAL SETUP AND RESULTS

The experimental setup of DC-DC boost converter based on voltage lift technique is done through two stages. First the program is written in micro C for generating gate pulses for switching devices. The program is verified and frequency is checked by simulating it in the Proteus software. The program is burned to the microcontroller (PIC16F877A) using the software micro programming suit for PIC. The switches used are MOSFET IRF540 along with its driver TLP250.

Table II Components used for prototype

Components	Rating
Inductors	1.2mH
Capacitor	110µF
Diode	IN5819
Controller	PIC16F877A
MOSFET	IRF540
Driver IC	TLP250

A prototype of DC-DC boost converter based on voltage lift technique is implemented. Control pulses for MOSFET switch is generated using PIC microcontroller. Control pulse is amplified by driver circuit composed of TLP250. It also provides isolation between control and power circuit. The experimental setup is shown in Fig.XI. It consist of control circuit, driver circuit and power circuit. Control circuit is composed of PIC microcontroller and its power supply. The pulses from microcontroller is amplified by driver circuit composed of TLP250. Power circuit the DC-DC boost converter based on voltage lift technique

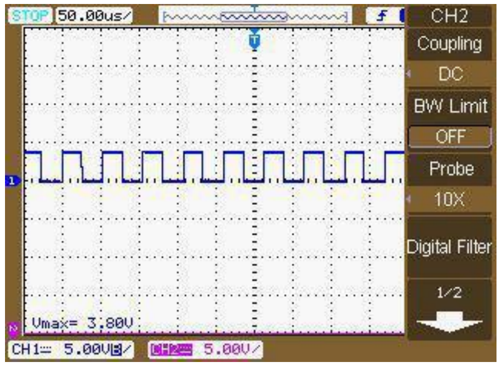


Fig. XII: Switching pulse waveform

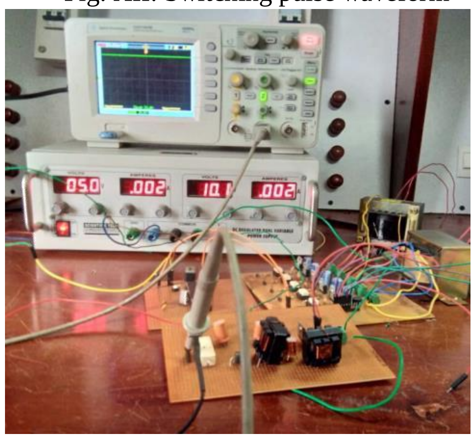


Fig. XI: Experimental setup

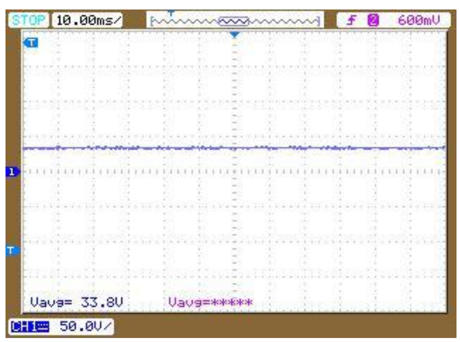


Fig. XIII: Output voltage waveform

The converter gives an output of 33.8V. Fig.XIII shows the output voltage waveform DC-DC boost converter based on voltage lift technique.

X. CONCLUSIONS

A new structure for non-isolated DC-DC boost converters with voltage-lift technique is introduced, its voltage and current equations of elements and semiconductor devices were extracted in continuous conduction mode and discontinuous conduction mode, and critical inductance relations were calculated. Following, the structure of converter and its efficiency was analyzed from the standpoint of number of switches, inductors, capacitors and diodes, and voltage gain at CCM. Considering Vi=12V, f=12KHz, D=50% and D'=50% , the average load voltage in CCM mode is 33.3V, which the theoretical and simulated results confirm fairly each other. Given that these voltage gain is achieved just by only one switch which turned on and turned off by specified duty cycle (dependent on voltage gain), then special controller system is not required.

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