

High Step Up Converter Using Voltage Multiplier Cells (VMC)

Md. Jahid Hasan¹, Ahmed Abdullah², Rafiqul Islam³, Mir Gulam Mohin Uddin⁴

¹American International University-Bangladesh, Dept. of Electrical and Electronic Engineering.
House # 9B, Road #29, Pallabi, Mirpur – 12, Dhaka - 1216, Bangladesh.

²American International University-Bangladesh, Dept. of Electrical and Electronic Engineering.
344 Polashbagh, West Rampura, Flat#A-2, Rampura, Dhaka-1219, Bangladesh.

³American International University-Bangladesh, Dept. of Electrical and Electronic Engineering.
House # 30/4, Dandabur NatunPara, Savarcantt. Savar, Dhaka, Bangladesh.

⁴American International University-Bangladesh, Dept. of Electrical and Electronic Engineering.
House-7, Road-2, Block-G/1, Mirpur-2, Dhaka, Bangladesh.

Abstract: *This paper introduces a new family of dc–dc converters based on the three state switching cell and voltage multiplier cells. A brief literature review is presented to demonstrate some advantages and inherent limitations of several topologies that are typically used in voltage step-up applications. In order to verify the operation principle of this family, the boost converter is chosen and investigated in detail. The behavior of the converter is analyzed through an extensive theoretical analysis, while its performance is investigated by experimental results obtained from a 1-kW laboratory prototype and relevant issues are discussed. The analyzed converter can be applied in uninterruptible power supplies, fuel cell systems, and is also adequate to operate as a high-gain boost stage with cascaded inverters in renewable energy systems. Furthermore, it is suitable in cases where dc voltage step-up is demanded, such as electrical fork-lift, audio amplifiers, and many other applications.*

Keywords: Boost converters, dc–dc converters, high voltage gain, voltage multiplier cells (VMCs)

1. Introduction

Depending on the application nature, several types of static power converters are necessary for the adequate conversion and conditioning of the energy provided by primary sources such as photovoltaic arrays, wind turbines, and fuel cells. Besides, considering that the overall cost of renewable energy systems is high, the use of high-efficiency power electronic converters is a must [1].

The literature presents numerous examples for applications where dc–dc step-up stages are necessary, e.g., audio amplifiers [2], uninterruptible power supplies (UPSs) [3], fuel cell powered systems [4], and forks lift vehicles [5], although many other ones can be easily found. Typical solutions include the use of low-frequency or high frequency power transformers to adjust the voltage gain properly. Besides, galvanic isolation may be necessary due to safety reasons [6].

The conventional boost converter can be advantageous for step-up applications that do not demand very high voltage gain, mainly due to the resulting low conduction loss and design simplicity [7]. Theoretically, the boost converter static gain tends to be infinite when duty cycle also tends to unity. However, in practical terms, such gain is limited by the I²R loss in the boost inductor due to its intrinsic resistance, leading to the necessity of accurate and high-cost drive circuitry for the active switch, mainly because great variations in the duty cycle will affect the output voltage directly [8].

Due to the importance of the conventional boost converter in obtaining distinct and improved topologies for voltage step

up applications, some techniques have been developed and modified with the aim of improving the characteristics of the original structure. Basically, two strategies are adopted for extreme values of duty cycle. Some arrangements available in the literature will be discussed as follows.

Cascading one or more boost converters may be considered to obtain high voltage gain. Even though more than one power processing stage exists, the operation in continuous conduction mode (CCM) may still lead to high efficiency [9]. The main drawbacks in this case are increased complexity and the need for two sets that include active switches, magnetic, and controllers. Besides, the controllers must be synchronized and stability is of great concern [10].

Due to high power levels and high output voltage, the latter cascaded boost stage has severe reverse losses, with consequent low efficiency and high electromagnetic interference (EMI) levels. Typical examples of such topologies are the single-switch quadratic boost converter and the two-switch three-level boost converter [11].

Stages with reduction of the current stress through the devices. Besides, the size of input inductors and capacitors is drastically reduced. The voltage stress across the main switches is limited to half of the output voltage for a single multiplier stage. However, high component count is necessary, with the addition of a snubber circuit due to the sum of the reverse recovery currents through the multiplier diodes and consequent increase of conduction losses.

The increase of the static gain by cascading several VMCs that operate based on the resonance principle. It is also shown that the input inductance is the same as that of a conventional

boost converter. Even though switching losses are minimized because there is zero-current switching (ZCS) turn-on of the main switch, conduction losses tend to increase due to the circulating reactive energy.

VMCs associated with the 3SSC [23], whose claimed advantages are the input current, is continuous with low ripple; the input inductor is designed for twice the switching frequency, with consequent weight and volume reduction; the voltage stress across the switches is lower than half of the output voltage, and naturally clamped by one output filter capacitor. As a disadvantage, a small snubber is necessary for each switch and one additional winding per cell is required for

The use of the 3SSC is associated with the following advantages: utilization of only one primary winding that allows the addition of a dc current blocking capacitor in series connection, in order to avoid the transformer saturation problem; less copper and reduced magnetic cores are involved during the transformer assembly; and the moderate leakage inductance of the transformer allows the reduction of overvoltage, and the commutation losses of the switches. The coupled inductor of the 3SSC has small size, because it is designed for half of the output power and for a high magnetic flux density, since the current through the windings is nearly continuous with low ripple.

This paper presents a topology for voltage step-up applications based on the use of multiplier cells constituted by diodes and capacitors. The converter is able to operate in overlapping mode (when a duty cycle D is higher than 0.5) and non overlapping mode (when a duty cycle D is lower than 0.5), analogously to other 3SSC-based structures. However, the study carried out in this paper only considers the operation with $D > 0.5$. The generic structure, which is valid for any number of cells, is initially presented, while the analysis is focused on structures with three cells, aiming to determine the stress regarding the elements that constitute the aforementioned configurations.

2. Proposed Topologies

For good operation of the VMC shown in Fig. 1(a), ac input voltage is required, which is an important requirement of this cell. Due to this fact, the use of the 3SSC depicted in Fig. 1(b) is considered because it generates such ac voltage across the terminals of the coupled inductor and the drain terminals of the controlled switches. For this reason, both cells are integrated leading to the proposed cell shown in Fig. 1(c). In the resulting cell, the controlled switches can be represented by MOSFETs, junction field-effect transistors, insulated gate bipolar transistors, bipolar junction transistors, etc. All the generated topologies present bidirectional characteristics.

The developed analysis considers the converter associated with three voltage multiplier cells and is detailed as follows. In order to better understand the operating principle of the structures, the following assumptions are made:

- 1) The input voltage is lower than the output voltage;
- 2) Steady-state operation is considered;
- 3) Semiconductors and magnetic are ideals;
- 4) Switching frequency is constant;
- 5) The drive signals applied to the switches are 180° displaced.

A. Operating Principle

The configuration that uses five voltage multiplier cells is represented in Fig. 2. The equivalent circuits that correspond to the converter operation presented in Fig.3.

First Stage

Switches $S1$ and $S2$ are turned on, while all diodes are reverse biased. Energy is stored in inductor L and there is no energy transfer to the load. The output capacitor provides energy to the load. See Fig.3. (a)

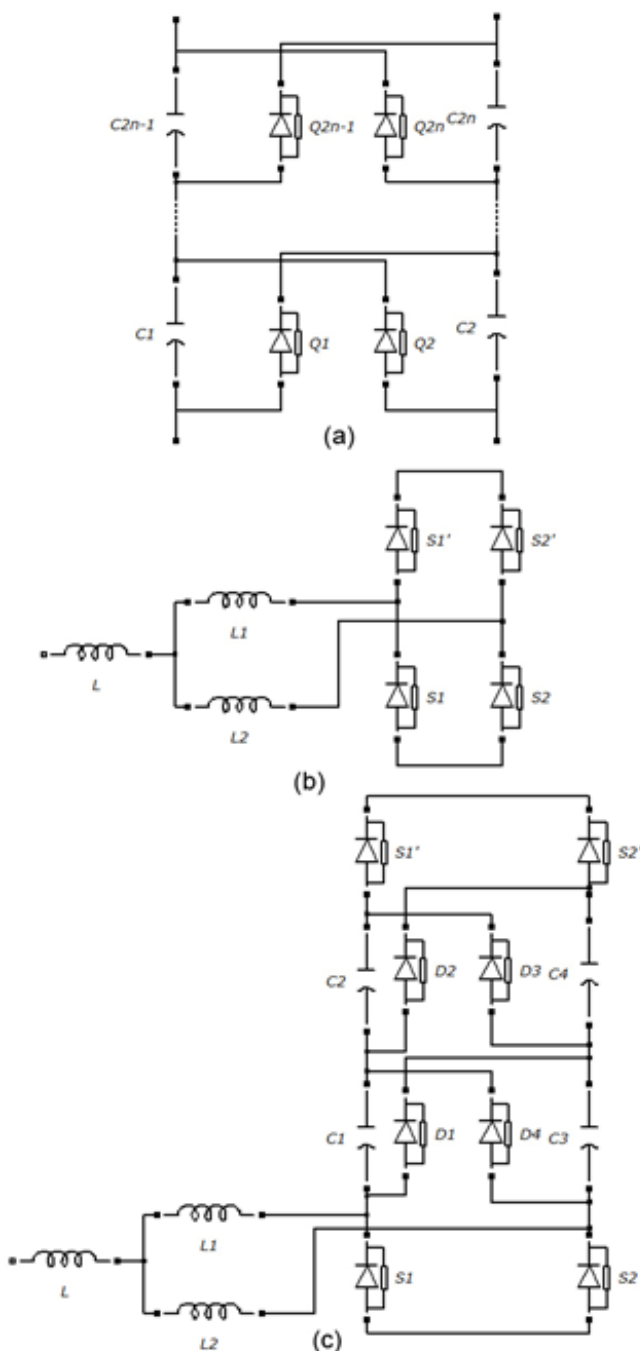


Figure 1: (a) Voltage multiplier cell (b) three-state switching cell (c) Resulting cell the autotransformer [23]

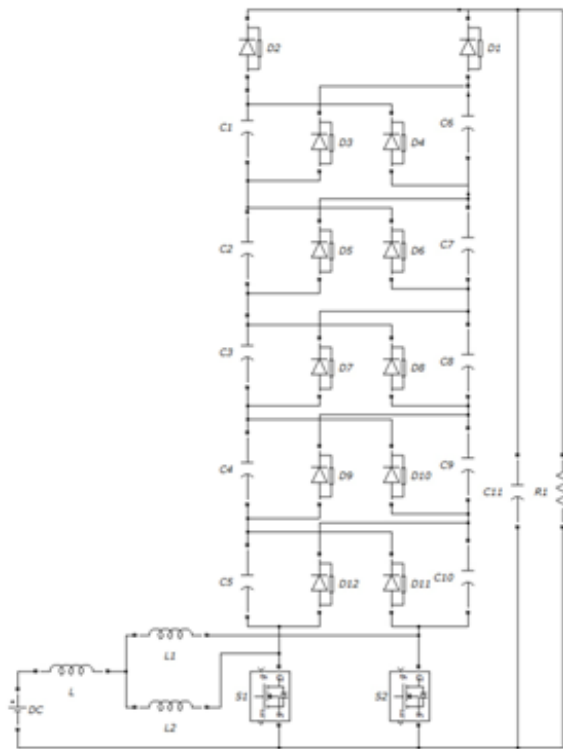


Figure 2: Boost converter using five VMCs

Second Stage Switches S1 is turned OFF, while S2 is still turned ON and Diode D9 is forward biased. There is no energy transfer to the load as well. Inductor L stores energy, capacitors C1 a C3, C5 and C7 are discharged, and capacitors C2, C4 and C6, C8, C10 are charged. See Fig.3. (b)

Figure 2 Operating stages: (a) first stage, (b) second stage, (c) third stage, (d) Fourth stage, (e) fifth stage, (f) sixth stage, (g) seventh stage, and (h) eighth stage. (i) Ninth stage. (j) Tenth stage. (k) Eleventh stage.

Third Stage

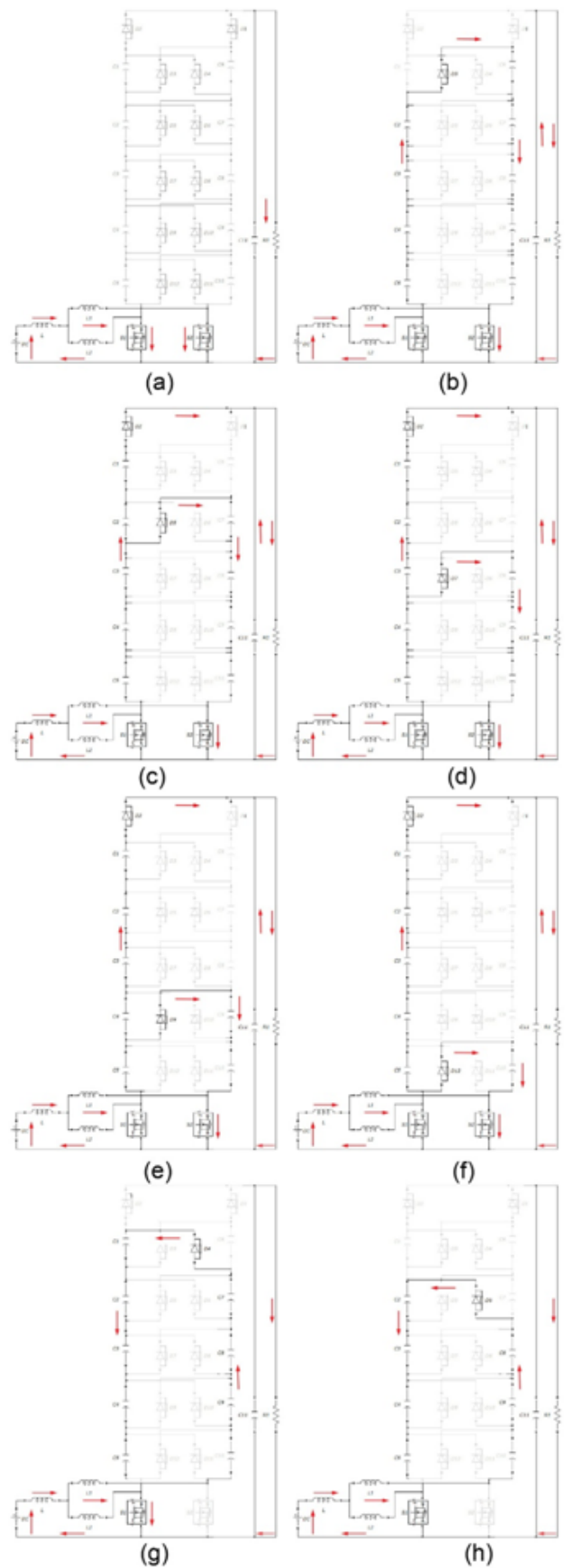
Switch S1 is turned OFF, while S2 is still turned ON and Diode D7 is forward biased, while all the remaining ones are reverse biased. Energy is transferred to the output stage through D11. Inductor L stores energy, capacitors C2, C4 and C6, C8 are charged. See Fig.3. (c).

Fourth Stage

Switch S1 is turned OFF, while S2 is still turned ON and Diode D5 is forward biased, while all the remaining ones are reverse biased. Energy is transferred to the output stage through D11. Inductor L stores energy, capacitors C1, C3, C5, C7, C9 are discharged, and capacitors C2, C4, C6 are charged. See Fig.3. (d)

Fifth Stage

Switch S1 is turned OFF, while S2 is still turned ON and Diode D3 is forward biased while all the remaining ones are reverse biased. Energy is transferred to the output stage through D11. Inductor L stores energy, Capacitor C1, C3, C5, C7, C9 are discharged, and capacitors C2, C4 are charged. See Fig.3. (e).



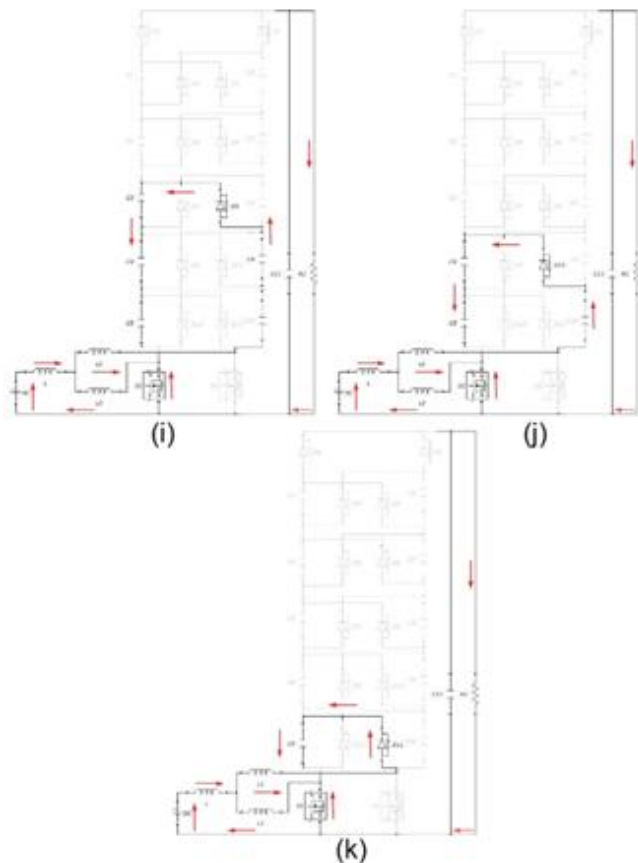


Figure 3: Operating stages: (a) first stage, (b) second stage, (c) Third stage, (d) Fourth stage, (e) fifth stage, (f) sixth stage, (g) seventh stage, and (h) eighth stage. (i) Ninth stage, (j) Tenth stage. (k) Eleventh stage.

Sixth Stage

Switch S2 remains turned ON, Diode D3 is reverse biased, and Diode D1 is forward biased while all the remaining ones are reverse biased. Energy is transferred to the load through D11. The inductor is discharged, and so are capacitors C1, C3 and C5, C7, C9 while C2 is charged. See Fig.3. (f).

Seventh Stage

Switch S2 is turned OFF and switch S1 is still turned ON. Diode D10 is forward biased while all the remaining ones are reverse biased. The inductor is charged by the input source, although capacitors C2, C4, C6, C8 are discharged and the capacitors C1, C3, C5, C7, and C9 are charged. See Fig.3. (g).

Eighth Stage

Switches S1 turned ON, Diode D8 is forward biased, while all the remaining ones are reverse biased. Energy is transferred to the output stage through D12. The inductor stores energy, and capacitors C1, C3, C5, C7, are charged. Capacitor C2 is discharged, and so are C4, C6, C8, and C10. See Fig.3. (h).

Ninth Stage

Switches S1 turned ON, Diode D6 is forward biased, while all the remaining ones are reverse biased. Energy is transferred to the output stage through D12. The inductor stores energy and capacitors C1, C3 and C5 are charged.

Capacitor C2 is discharged, and so are C4, C6, C8, and C10. See Fig.3. (i).

Tenth Stage

Switches S1 turned ON, Diode D4 is forward biased, while all the remaining ones are reverse biased. Energy is transferred to the output stage through D12. The inductor stores energy, and capacitors C1 and C3 are charged. Capacitor C2 is discharged, and so are C4, C6, C8 and C10. See Fig.3. (j).

Eleventh Stage

Switches S1 turned ON, Diode D2 is forward biased, while all the remaining ones are reverse biased. Energy is transferred to the output stage through D12. The inductor stores energy and capacitor C1 is charged. Capacitor C2 is discharged, and so are C4, C6, C8, and C10. See Fig.3. (k).

3.Simulation Results

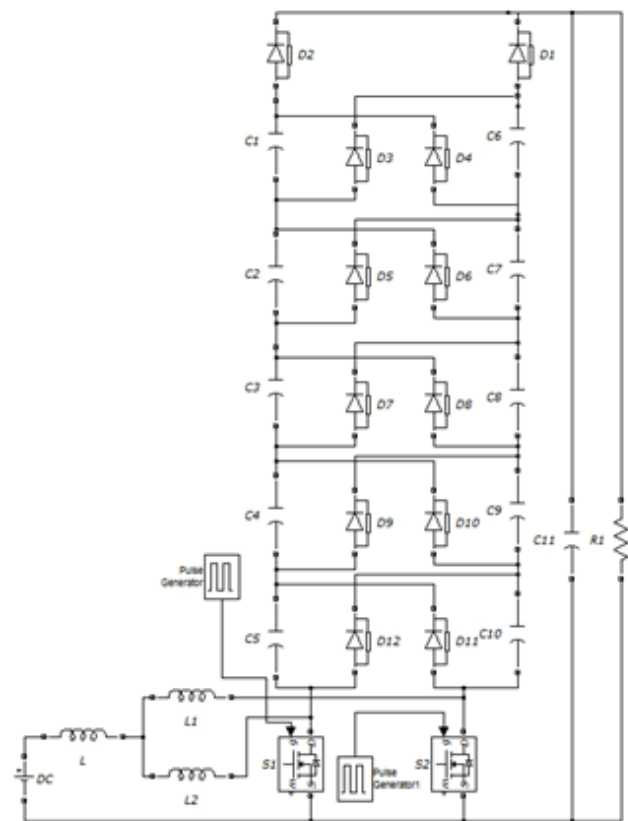


Figure 4: Five VMC Simulation

Figure 4 shows the simulation model of 5 VMC method.

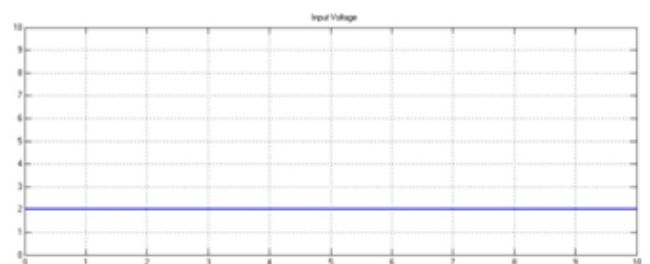


Figure 5: Input voltage

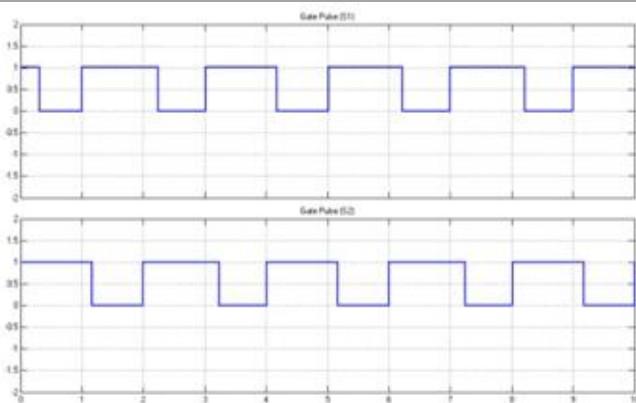


Figure 6: Triggering pulses

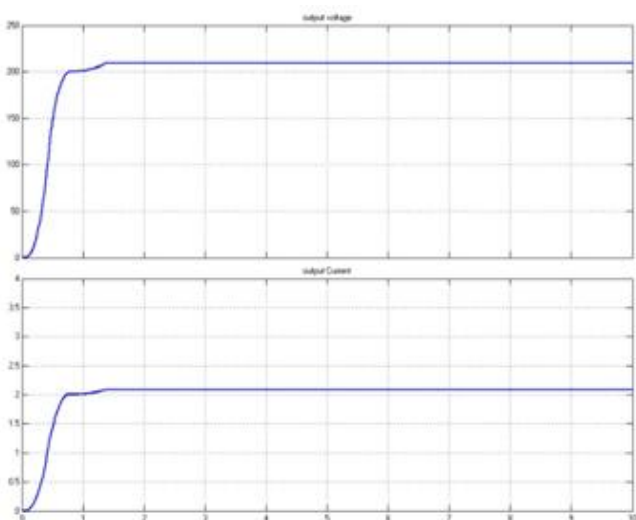


Figure 7: Output voltage and current

4. Design Calculations

Inductance:

$$L = (1-D) \cdot V^2$$

$$D = \text{TON} / \text{TOTAL TIME} = 20 / 40 \times 10^{-6}$$

$$D = 0.5 \times 10^{-6}$$

$$L = (1 - 0.5 \times 10^{-6}) \cdot (54)^2 = 0.5 \cdot 10^{-6} \cdot 2916$$

$$L = 1500 \mu\text{H}$$

$$L1 = L/2 = 1500/2$$

$$L1 = 750 \mu\text{H}$$

$$L1 = L2$$

$$L2 = 750 \mu\text{H}$$

Where D = Duty ratio

V=Initial voltage.

Filter Capacitance:

$$2C0 = (1-D0) \cdot V_{\text{OUT}} \cdot \text{TON} \quad 2C0 = (1-0.5) \cdot 400 \cdot 20 \times 10^{-6}$$

$$C0 = 2000 \mu\text{F}$$

Where Ton=on time.

Filter Resistor:

$$R = V/I = 400/8 = 50 \Omega$$

$$R = 50 \Omega$$

Voltage Dividing Capacitor, $C = 2V_{\text{IN}} = 2 \cdot 54 = 108$

We using 8 Capacitor, so divide by 8

$$C = 108/8 = 13.5 \text{ C} \sim 10 \mu\text{F}$$

5. Conclusion

This paper has proposed six generalized non isolated high gain voltage dc-dc converters. To verify the principle operation of the generated structures, the boost converter was chosen. The topology is adequate for several applications such as photovoltaic systems, fuel cell systems, and UPSs, where high voltage gain between the input and an output voltage is demanded. An important characteristic that can be seen in the experimental results is the reduced blocking voltages across the controlled switches compared to similar circuits, allowing the utilization of MOSFETs with reduced on resistance.

Besides, the advantages of the 3SSC are also incorporated into the resulting topology, e.g., the current is distributed among the semiconductors. Furthermore, only part of the energy from the input source flows through the active switches, while the remaining part is directly transferred to the load without being processed by these switches, i.e., this energy is delivered to the load through passive components, such as the diodes and the transformer windings.

It is simple to conclude that this paper introduces a simple Soft-Switched technique circuit with the High Step-up DCDC Converter. It is simulated with R-Load. Voltage Conversion Ratio is also compared with the Conventional Converter which proves that Voltage Gain is almost doubled in the designed converter. The following are advantages:

- The turn-on and turn-off of the components are reduced due to Soft Switching technique employed.
- Voltage Conversion Ratio is almost doubled compared to the conventional boost converter.
- The duty cycle loss is much reduced resulting in the increased step-up ratio.

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Rafiqul Islam is currently doing his B.Sc in Electrical & Electronic Engineering from American International University-Bangladesh (AIUB). Currently, he is doing research on Power and Energy.



Mir Gulam Mohin Uddin was born in Chittagong, Bangladesh, in 1993. He completed his S.S.C. and H.S.C. from Chittagong Municipal Model High School and Hajera-Taju University College, in 2008 and 2010 respectively. He received the Bsc. degree in Electrical & Electronics Engineering from American International University- Bangladesh, in 2014.

Author Profile



Md. Jahid Hasan is under graduated from American International University Bangladesh (AIUB) in department of Electrical and Electronic Engineering. He is currently a Research Assistant with the Department of Electrical Engineering. His main research interests include power electronic converters, Renewable Energy and Technology and Organic Circuitry.



Ahmed Abdullah earned BSc from American International University-Bangladesh under the department Electrical and Electronics Engineering. He primarily develops projects on embedded system, but also has experience with Renewable Energy, Power System Protection.