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# A Voltage-Lift DC-DC Converter with Large Conversion Ratio

Ho-Yeon Kim*, Eun-A Moon**, Yong-Mi Lee*, Youn-ok Choi***★

## Abstract

A extension of the high boost voltage-lift DC-DC converter with large conversion ratio has been proposed in this paper. The proposed extension is combined the switched-inductor cell (SL-cell) and modular voltage cell (MV-cell). The proposed structure can achieve the large voltage conversion without high duty-cycle and the low voltage of the components. Moreover, the PID controller for novel SL-MV voltage-lift DC-DC converter also introduces. This technique a good-performance output voltage can kept constant with an good transient performance when the output load is suddenly changed. In order to prove the theoretical analysis, the experimental setup has been built for the DC load of 150[Ω] and 300[Ω]. In addition, the transient of output voltage has been tested to determine the controller. Experimental results validate the effectiveness of the theoretical analysis proving the satisfactory converter performance.

*Key words : tranformerless converter; high-voltage gain; switched-inductor; voltage-lift; duty ratio*

## Ⅰ. Introduction

Nowadays, energy from renewable sources such as wind power, photovoltaic power, and fuel cells has become the best solution to generate clean electric energy. However, the demerit characteristics of these energies is the low-output voltage and instability. Thus, a DC-DC converters [1-2] with a high boost voltage conversion is used to boost the low output voltage of the clean energy to high voltage. Fig. 1 indicates a block diagram of the power-conversion system. A high gain DC-DC converter is used to boost a low voltage into a high voltage dc bus.

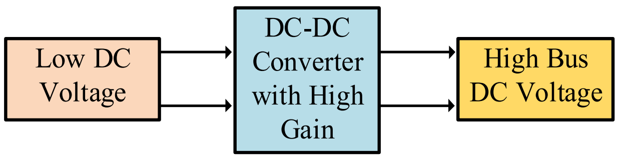


Fig. 1. Block diagram of power-conversion system.

Various DC-DC converter topologies have been researched and obtained a high-voltage gain in both isolated and non-isolated topologies. For the isolated DC-DC converter topologies [3-6], to boost low input voltage into high output voltage, a high frequency transformer is used. As a result, the cost, weight and volume of converter circuit are significantly risen. Furthermore, the leakage

* Dept. of Electrical Engineering, College of Korea Polytechnies
** Dept. of Electrical Engineering, Chosun College of Science & Technology
*** Dept. of Electrical Engineering, Chosun University
★ Corresponding author
E-mail : yochoi@chosun.ac.kr, Tel : +82-62-230-7175
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inductances can be caused a voltage spike on switches. Due to the transformer losses, leakage inductance and large volume/weight of the converter, the transformer-based topologies is difficult to obtain a high efficiency and low cost like non-isolated topologies. For conventional non-isolated DC-DC converters, an extremely high duty cycle is required to obtain a high voltage gain. Recently, many high boost DC-DC converters have been proposed in [7-20] to obtain a high voltage gain without using high duty cycle. In the high boost converters with non-isolated structure can obtain the high voltage gain; some techniques were proposed and used such as cascaded technique [10], switched-inductor technique [11], switched-capacitor techniques [12], interleaved [13]-[14], and voltage-lift [15-16] techniques have been introduced. In switched-capacitor technique [8], by combining several switches and capacitors with minimum inductor achieving a higher output voltage can be achieved. The voltage-lift DC-DC converter and it's extension have been proposed in [21], which can increase the voltage gain. However, it is just verified with the simulation.

This paper presents the novel SL-MV voltage-lift DC-DC converter with PID controller was determined with the voltage gain ratio will be improved and using the small duty cycle. Moreover, the PID controller with the experimental has been shown.

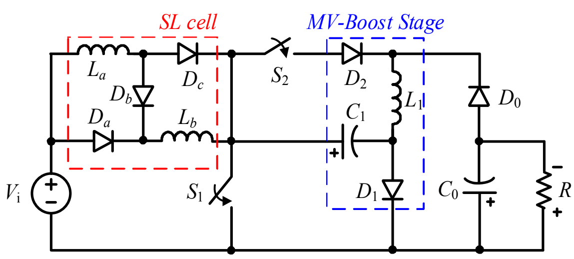


Fig. 2. Voltage-lift high boost DC-DC converter in [21].

## II. Novel Voltage-lift DC-DC Converter

Fig. 2 shows the voltage-lift DC-DC converter in [21]. It consists of one SL cell $L_a, L_b, D_a, D_b$, and $D_c$, two power switches $S_1 - S_2$, modular voltage boost stage $L_1, D_1, D_2$ and $C_1$, one diode $D_0$, one capacitors $C_0$. Fig. 3 shows the key waveforms of the voltage-lift converter operating in the CCM.

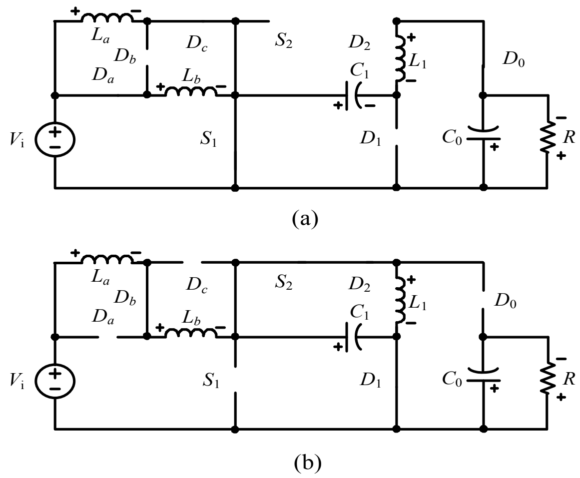


Fig. 3. Operating modes of the suggested converter: (a) state 1 and (b) state 2.

### 1. Derivation of novel voltage-lift DC-DC converter

Fig. 4 represents the operating state of the suggested converter. When $S_1$ is turned "ON" with DT. The $D_a, D_c$ diodes are ON, while the $D_b$ diode is OFF. The $D_0$ diode is forward-biased and $D_1$ is OFF. We have

$$\begin{cases} L_a \dfrac{di_{La}}{dt} = L_b \dfrac{di_{Lb}}{dt} = V_i \\ L_1 \dfrac{di_{L1}}{dt} = V_{C1} - V_o. \end{cases} \quad (1)$$

When $S_1$ is switched "OFF" and $S_2$ is switched "ON"; the $D_0$ diode is OFF while the $D_1$ diode is ON. We have

$$\begin{cases} L_a \dfrac{di_{La}}{dt} + L_b \dfrac{di_{Lb}}{dt} = V_i - V_{C1} \\ L_1 \dfrac{di_{L1}}{dt} = V_{C1}. \end{cases} \quad (2)$$

The voltage gain of the converter is given

$$G = \frac{1+D}{D(1-D)}, \tag{3}$$

## 2. Derivation of novel voltage-lift DC-DC converter

The novel voltage-lift DC-DC is shown in Fig. 4. It can be extended to produce a higher voltage conversion ratio by cascading more SL and MV cells, and the structure is shown in Fig. 5. It will be composed of SL-cell with one inductor and three diodes, and MV-cells with one inductor, one capacitor and two diodes.

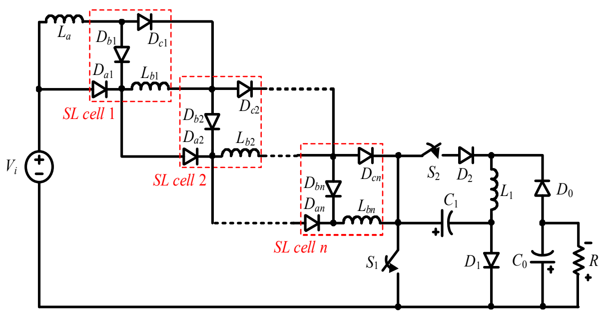


Fig. 4. Novel voltage-lift DC-DC converter with with n SL-cells.

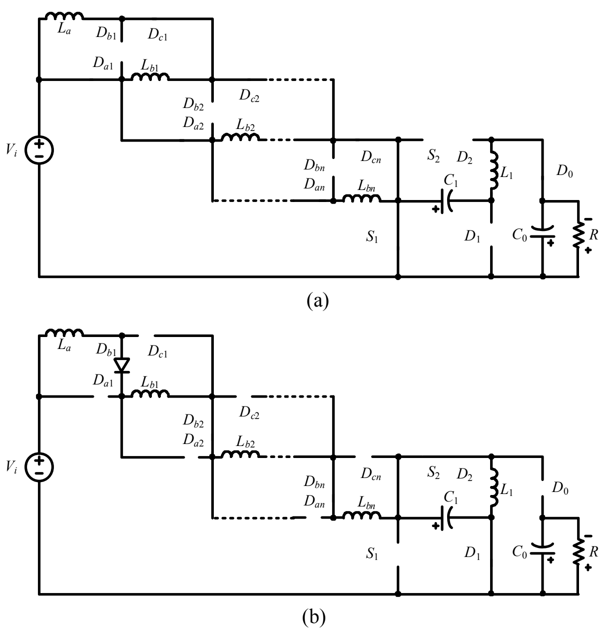


Fig. 5. Operating modes of the novel voltage-lift DC-DC converter with n SL-cells: (a) $S_1$ is ON, $S_2$ is OFF and (b) $S_1$ is OFF, $S_2$ is ON.

In the operating analysis, $S_1$ is ON and $S_2$ is OFF, $D_1$ and $D_2$ are OFF. The diodes $D_{bn}$ in SL-ells are OFF, diodes $D_{an}$ and $D_{cn}$ are ON. In this case, $L_a$ and $L_{b1,}...L_{b(n+1)}$ are in series connection. When $S_1$ is OFF and $S_2$ is ON, $D_1$ and $D_2$ are ON. The diodes $D_{bn}$ in SL-cells are ON, diodes $D_{an}$ and $D_{cn}$ are OFF. In this case, $L_a$ and $L_{b1,}...L_{b(n+1)}$ are in parallel connection. The voltage gain of the novel voltage-lift DC-DC converter with n SL-cells is given

$$V_o = \frac{1+nD}{D(1-D)} V_i \tag{4}$$

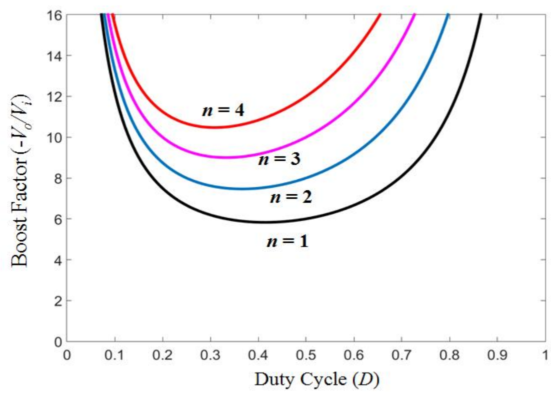


Fig. 6. Voltage gain comparison when n = 1, 2, 3, 4.

## 3. The novel voltage-lift DC-DC converter with SL-MV cells

The voltage gain of the suggested converter can be improved by adding m-SL cells and m-stages. The switched-inductor cell can connect in series with nth times the voltage stress of diodes in SL-cell are decreased. Furthermore, the stage $m_{th}$ can connect in series where the voltage gain can increase with n times compared to the voltage gain of the basic converter.

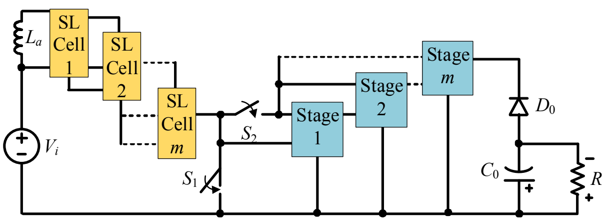


Fig. 7. Novel voltage-lift DC-DC converter with with SL-MV cells.

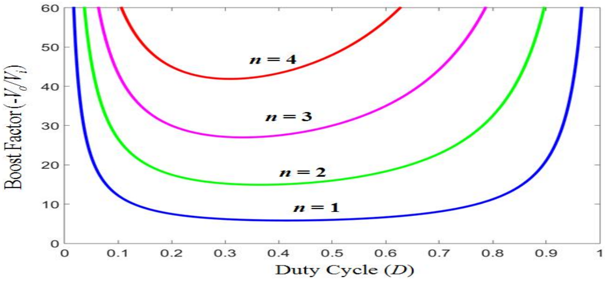


Fig. 8. Voltage gain comparison when m = 1, 2, 3, 4.

## Ⅲ. Control algorithm for novel voltage-lift DC-DC converter with SL-MV cells

Figure 9 demonstrates the block diagram controlled boost type DC-DC converter and the scheme of digital control circuit. In here, the power circuit of the DC-DC converter are included switches, diodes, inductors and capacitors. The output current and voltage is read by voltage and current sensor circuits. These analog signals are thrown the analog to digital block of the digital signal processor to convert the analog signal to the digital signal. Moreover, the pulse width modulation signal will be generated by the PWM generator of the digital signal processor with the switching frequency $f_s$. The switching frequency of the switching devices in power circuit will operate in the frequency of $f_s$. The control calculation is updated by each sampling point.

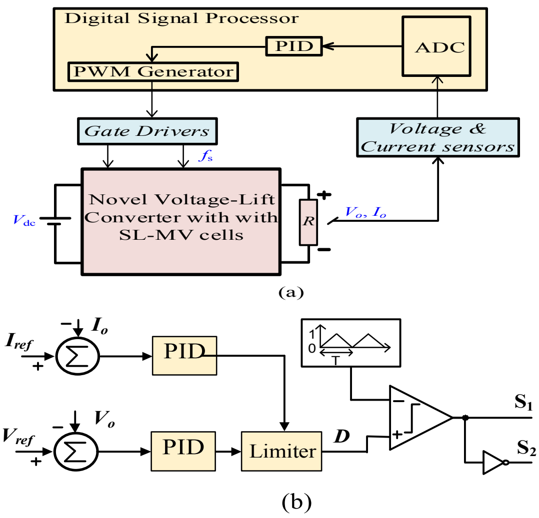


Fig. 9. Block diagram. (a) PID controlled DC-DC converter; and (b) Output voltage and current control algorithm.

## Ⅳ. Experimental Verification

A laboratory prototype was set up to validate the experimental verification. Figure 9 presents a prototypal photograph and parameters for experiment were indicated in the Table 1. In the switched-nductor cell, two inductors are 1 mH and three diodes STTH3002C were used. Two MOSFETs IXTR48P20P was used for switch $S_1$ and $S_2$. One inductor of 2 mH, and one capacitor of 220 $\mu$F used for $L_1$ and $C_1$. Three diodes STTH3002C were used for $D_0$, $D_1$ and $D_2$. The PWM signals are generated by Digital Signal Processor of Texas Instrument TMS320F28027 for two MOSFET $S_1$ and $S_2$.

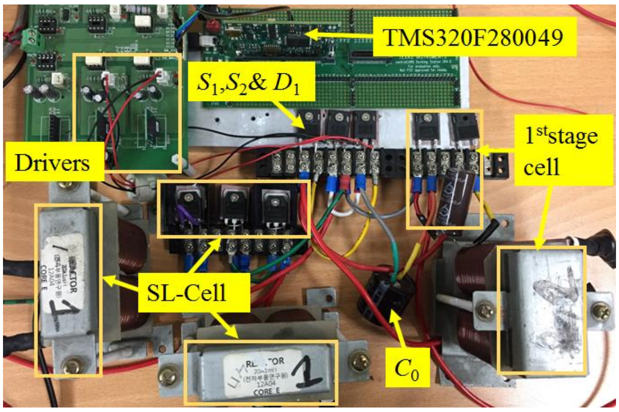


Fig. 9. Prototypal photograph.

Table 1. List of parameters.

| Parameter | | Values |
|---|---|---|
| Input DC voltage (Vi) | | 10 [V] - 20 [V] |
| Output voltage (Vo) | | 120 [V] |
| Resistor | | 150-300 [Ω] |
| Inductors | La= Lb | 1 [mH] |
| | L1 | 2 [mH] |
| Capacitors | C1 | 220μF/200 [V] |
| | C0 | 330 μF/200 [V] |
| Operating frequency (fs) | | 10 [kHz] |
| MOSFETs (S1, S2) | | IXTR48P20P |
| Diodes (Da-Db-Dc-D0-D1-D2) | | STTH3002C |

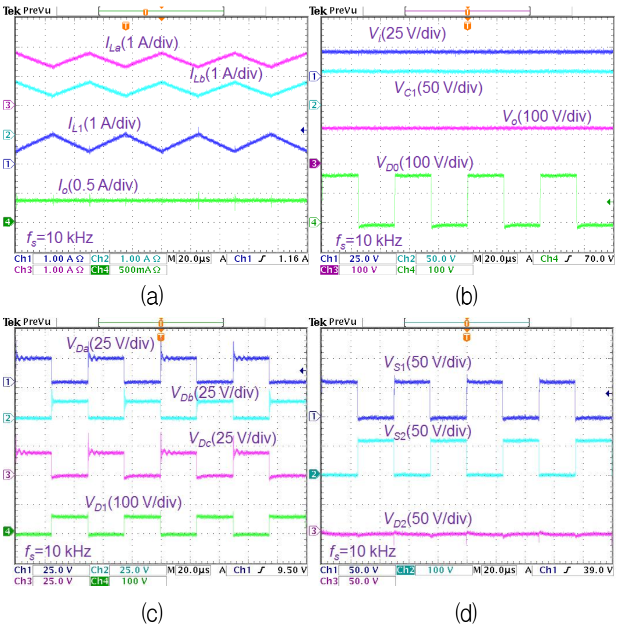


Fig. 10. Experiment waveforms when $V_i$=20[V], $R$=300[Ω].

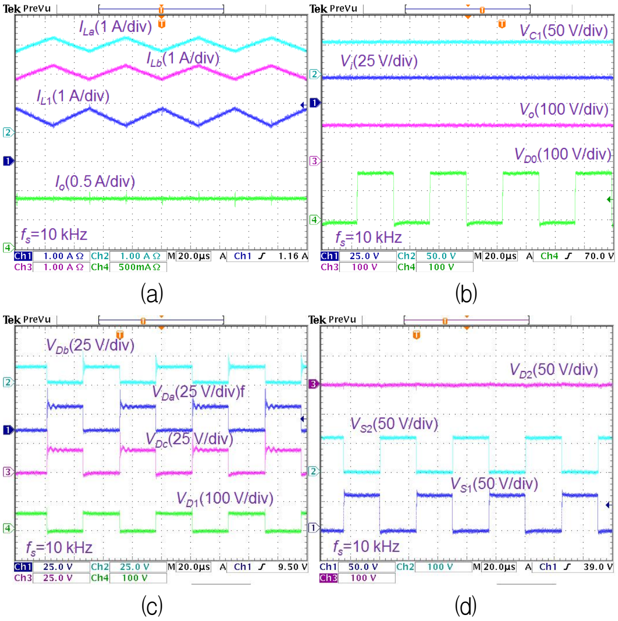


Fig. 11. Experiment waveforms when $V_i$=20[V], $R$=150[Ω].

In the experimental verification, the input voltage is set to 20[V]. The operating frequency of semiconductor devices are 10 kHz. The output voltage of 120[V] was used for the resistive load is 150[Ω] and 300[Ω], as shown in Figures 9-10. In the Figures 9-10: (a) inductors La, Lb, L1 current, output current, (b) input voltage, capacitor C1 voltage, output voltage, diode D0 voltage; (c) diodes Da, Db, Dc and D1 voltage; and (d) diode D2, switches S1 and S2 voltages. The inductor L1 current is linearly increased at D・T when MOSFET S1 is ON. In addition, the inductor L1 current is gradually decreased during (1-D)・T. The voltage of the experimental capacitor C1 is boosted to 58[V].

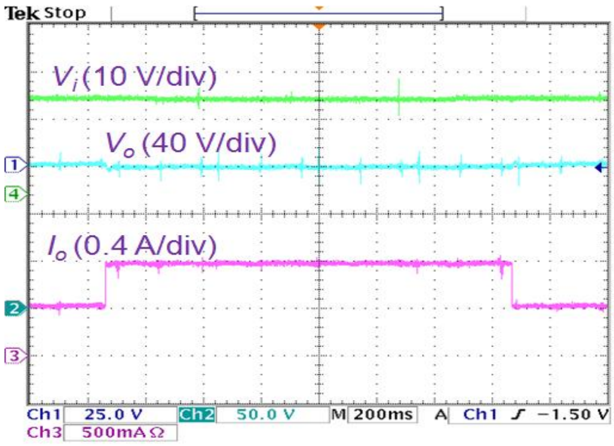


Fig. 12. Experimental waveform of the converter when load is suddenly changed. From top to bottom: input voltage, output voltage, load current.

Figure 12 Illustrates the dynamic response of the novel DC-DC converter with SL-MV cells when the load is suddenly changed. As shown in Figure 12, we can see that the load voltage is maintained constant at 120[V], even though the resistive load is changed from 150[Ω] to 300[Ω] and vice versa.

## Ⅴ. Conclusions

The novel high gain DC-DC boost converter based on the switched-inductor cell and modular voltage cell was presented in this paper. The novel converter can give the high voltage gain with combination of n switched-inductor cell and n-stage with a modular voltage cell. The operating mode of the converter adopting an SL cell and MV cell was analyzed, and the experimental results have been given to verify the analysis and merits of the converter. Moreover, the novel SL-MV voltage-lift DC-DC converter with PID controller was validated to determine the transient response for change in load conditions.

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## BIOGRAPHY

**Ho-Yeon Kim** (Member)

1999 : BS degree in Economics, Chonnam National University.
2011 : MS degree in Software Engineering, Honam University.
2007~2011 : DELLEMC Sr. Engineer
2019 : PhD degree in Electrical Engineering, Chosun University

**Eun-A Moon** (Member)

1991 : BS degree in Electrical Engineering, Chosun University.
2005 : MS degree in Electrical Engineering, Chosun University
2014 : PhD degree in Electrical Engineering, Chosun University

**Yong-Mi Lee** (Member)

2000 : BS degree in Electrical Engineering, Korea University of Technology and Education.
2010 : MS degree in Electrical Engineering, Chonnam National University.
2015 : PhD degree in Electrical Engineering, Chosun University.

**Youn-Ok Choi** (Member)

1995 : BS degree in Electrical Engineering, Chosun University.
1997 : MS degree in Electrical Engineering, Chosun University
2003 : PhD degree in Electrical Engineering, Chosun University