Two Level DC to DC Boost Converter with Improved Voltage Gain

Leardpan Piansangsan[1] and Singthong Pattanasethanon[2*]

[1]Faculty of Engineering, Pitchayabundit College, Nongbualamphu, Thailand
[2]Department of Electronics and Telecommunication Engineering, Rajamangala University of Technology Thanyaburi, Pathumthani, Thailand

sing191@hotmail.com* and singthong.p@en.rmutt.ac.th

Abstract. *This paper presents a 2x DC-DC multilevel boost converter (MBC) using an auxiliary circuit for increasing the voltage gain. The MBC circuit consists of a semiconductor switch, an inductor, three diodes and three capacitors. The auxiliary circuit consists of one switch, 2 diodes and 2 capacitors. The main switch of the converter can be complete operated at the switching frequency of F. While the auxiliary switch is operated at the switching frequency of F/2 and at less 50% of duty cycle. Timing diagrams of the switching pattern are used to describe the mode of operation at a particular time. PSPICE simulated is presented to prove the proposition's principle.*

Keywords:

2 level DC-DC boost converter, multilevel

1. Introduction

Nowadays, renewable energy such as solar energy has been increased in attention. However, converting solar energy into electricity using solar panels usually provide low output DC voltage, which may not fit to directly supply the conventional AC lines. Therefore, the output voltage has to be boosted to higher levels suitable for feeding the household appliances or connected to the power grid.

A DC to DC boost converter is normally employed to step up the DC voltage for the solar panels in most cases. This is because it can regulate the output voltage with large difference between the input and output voltage levels, by mean of high voltage gain. However, in order to achieve that, a switch in the converter must operate with extreme duty cycle and stress [1] or else the transformer should be used, but may have some problems regarding large size and heavy. As a result, the converter is still popular but would require new designs to allow higher switching frequency and thus smaller circuit structure and low voltage stress on the switching devices could be achieved [2].

These recent years, several new DC-DC Multilevel Boost Converters (MBC) with high voltage gain have been proposed [1]-[5]. One of those MBC converters would be a 2xDC-DC MBC. This converter type has simple structure with only one switch, one inductor, three diodes and three capacitors, but can provide very high voltage gain as expressed in (1); where D is the duty cycle of the switch. In addition, the converter also operates continuous input current mode, large conversion ratio without extreme duty cycle, no need transformer, high switching frequency operation and modular based-structure, where the users can increase the output voltage by just adding more capacitors and diodes without changing the main circuit, Fig. 1 shows the circuit structure of the conventional 2x DC-DC MBC.
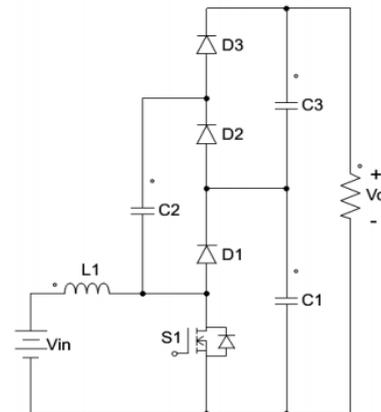

Fig. 1: a conventional 2x DC-DC MBC converter [1]-[5]

$$\frac{Vo}{Vin} = \frac{2}{1-D} \qquad (1)$$

This paper proposes a novel topology of a 2x DC-DC MBC with an additional auxiliary switching circuit, which provides higher voltage gain than the conventional circuit. The PSpice simulation program was used to examine the feasibility of the proposed MBC.

2. Proposed 2x DC-DC multilevel boost converter

2.1 Circuit Description

Fig.2 depicts the proposed circuit. It is 2x DC-DC MBC based on 2 electronics switches, 1 inductor, 5 diodes

and 4 capacitors. The main driven switch S1 and the auxiliary driven switch S2 are operated at its particular switching frequencies, the main S1 is driven at frequency of F hertz while the auxiliary switch S2 is driven at F/2 hertz.
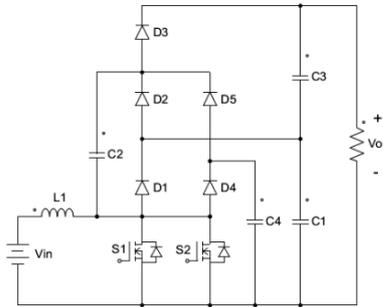

Fig. 2: Proposed 2x DC-DC boost converter

The average output power across the load-resister can be controlled simply by only adjusting the duty cycle of the main switch S1. The duty cycle of an auxiliary switch S2 have to set more than 50% in order to share the current b e t w e e n   m a i n   s w i t c h   S 1 .

2.2 Modes of operation

The operations of a proposed circuit have to be described in 4 modes. The switching pattern of each mode presents in Fig. 3 and the schematic circuit of each mode are show in Fig.4

Mode 1: (t_0-t_1)

Both the main switch S1 and an auxiliary switch S2 are in ON state, the inductor is connected to the voltage source. Current flows through an inductor L1, switch S1 and S2. Both capacitors C1 and C4 charge C2 through the D2 and D5 respectively, whilst capacitor C3 discharges through the load. This mode energy is stored in the inductor. The expressions are.

$$V_{in} - V_L - V_{sat} = 0 \qquad (2)$$
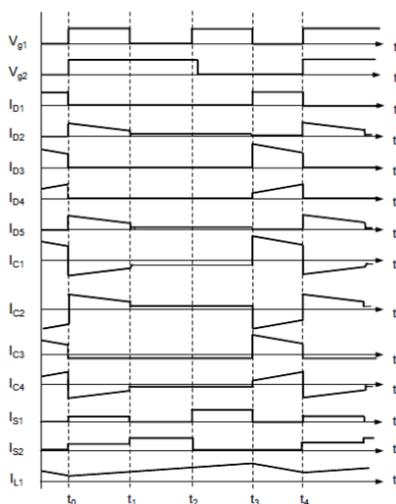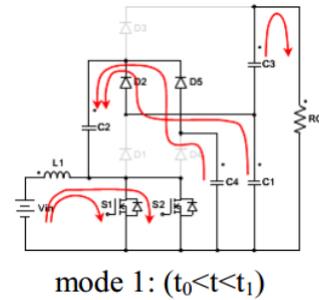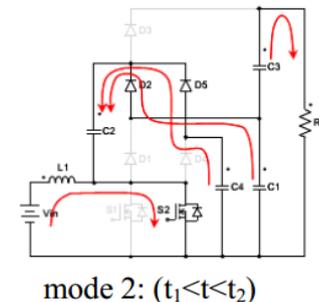

Fig. 3: Switching patterns of a proposed 2x DCDC boost converter

mode 1: ($t_0 < t < t_1$)

(a)

mode 2: ($t_1 < t < t_2$)

(b)

mode 3: ($t_2 < t < t_3$)

(c)

mode 4: ($t_3 < t < t_4$)
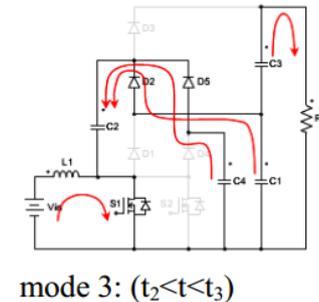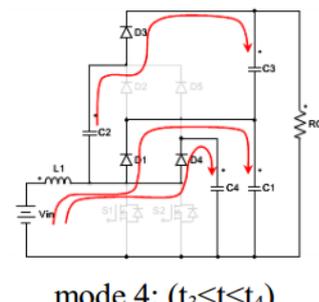
(d)

Fig. 4: Operation modes of proposed 2x DC-DC MBC

The inductor voltage is equal to

$$L_{ion} = V_{in} t_{on} \qquad (3)$$
$$V_{Lon} = V_{in} t_{on} \qquad (4)$$

Mode 2: (t₁-t₂)

The main switch S1 is turned off while an auxiliary switch S2 still turned on. This mode energy is mostly stored in the inductor. The inductor voltage is equal to (4) that is,

$$V_{Lon} = V_{in}\ t_{on} \tag{5}$$

Mode 3: (t₂-t₃)

The main switch S1 is turned on but an auxiliary switch S2 is turned off. This mode energy is remained store in the inductor. The inductor voltage is equal to (5) that is,

$$V_{Lon} = V_{in}\ t_{on} \tag{6}$$

Mode 4: (t₃-t₄)

All driven switches are turned off, the energy in the inductor is transferred to the capacitors C1 and C4 through D1 and D4 respectively. Capacitor C3 is charged, expressing by the following equations:,

$$V_{in} - V_L - V_C = 0 \tag{7}$$

$$V_{in} - \frac{L \times i_{off}}{t_{off}} - V_C = 0 \tag{8}$$

V_C is the voltage across C1, also the voltage across C4. The inductor voltage is equal to

$$V_{Loff} = (V_{in} - V_C) \times t_{off} \tag{9}$$

Giving T as the total switching period which is equal to the summation of time period from mode 1 to mode 4. The average voltage in the inductor can be expressed as,

$$\langle V_L \rangle_T = \frac{2 \times (V_{in} \times t_{on}) + (V_{in} \times t_{on}) + (V_{in} - V_C) \times t_{off}}{T} \tag{10}$$

Where, the duty cycle $D = t_{on}/T = 1 - t_{off}/T$

From Fig.3, at less one switch is turned on between time t0 to t2, as explained the first 50% of period T always ON state. So that;

$$\langle V_L \rangle_T = V_{in} + V_{in} \times D + (V_{in} - V_C) \times (1 - D) \tag{11}$$

$$\langle V_L \rangle_T = 2 \times V_{in} - V_C \times (1 - D) \tag{12}$$

Assume that the average voltage across the inductor over one switching cycle is equal to zero. From (12), the voltage in capacitor can be expressed as,

$$V_C = \frac{2 \times V_{in}}{1 - D} \tag{13}$$

This V_C is the first level of boost converter. The voltage multiplier makes all the left capacitor (C2 and C3) to charge to the same voltage, then the output voltage across the load can be expressed as;

$$V_o = V_{C1} + V_{C3} \tag{14}$$

$$V_o = \frac{2 \times V_{in}}{1 - D} + \frac{2 \times V_{in}}{1 - D} \tag{15}$$

$$V_o = \frac{4 \times V_{in}}{1 - D} \tag{16}$$

An equation (16) expresses the relationship between output voltage and input voltage. The input DC current can be expressed in terms of the input voltage as;

$$I_L = \frac{16 \times V_{in}}{R_o \times (1 - D)^2} \tag{17}$$

From (17), it can be seen that the input current can be controlled with D in the PWM

3. Results and Discussions

The simulation of the proposed 2x DC-DC MBC model was examined using the ORCAD PSPICE simulation software. The parameters involved in this simulation were L1=500 µH, C1=C2=C3=C4= 220 µF, R=500Ω, and Vin = 12 volts. The frequency of PWM of S1 was equal to 40 kHz while the frequency of S2 was 20 kHz with 50% of duty cycle. Fig.5 shows the corresponding simulated waveforms.
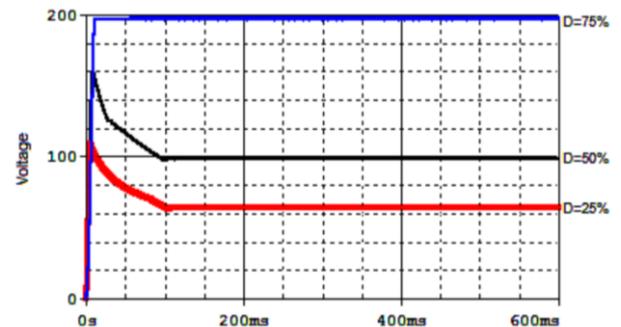

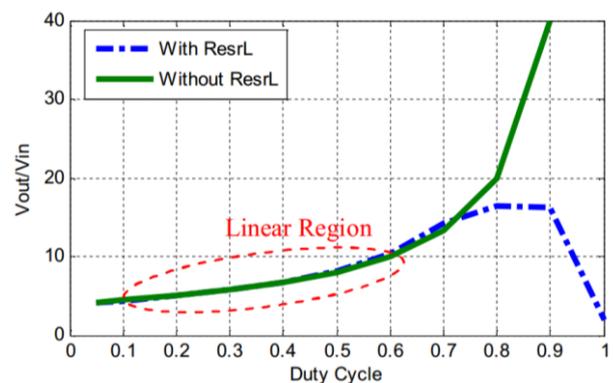**Fig. 5:** Transient traces of the simulated model based output voltage

Fig. 6: Voltage gain against duty cycle

Fig.6 shows the difference between ideal and simulated boost convert ratios, which were plotted against the operating duty cycles. The simulated boost converter was limited by the parasitic resistance R_{esrL} , which was the resistance represented within the input inductor. It can be seen in the Fig. 6 that a quasi-linear region appeared when the duty cycle was around 0.5. In fact, this is the best duty cycle that provided the best operation for the proposed circuit.

4. Conclusion

The aim of this paper is to develop and implement a 2x DC-DC multilevel boost converter (MCB) circuit. The circuit consists of an additional auxiliary circuit, which is constructed by one switch, one capacitor, and two diodes to the based circuit and setting its PWM frequency at a half of the based circuit's frequency with more than 50% of duty cycle. This helps boosting output voltage gain from the conventional MCB circuit of 2/(1-D) to 4/(1-D) by this proposed circuit. The simulated results confirmed the feasibility of the proposed circuit. This new designed 2x DC-DC MBC could be applied to increase the DC link voltage level of the output voltage of the PV or wind generation system.

5. Acknowledgement

6. References

[1] Rosas-Caro, J.C., Mayo-Maldonado, J.C., Salas-Cabrera, R., A family of DC-DC Multiplier Converters, International Association of Engineers, Vol. 19 Issue 1, pp.57, 2011.

[2] Rosas-Caro, J.C., Ramirez, J.M., Peng, F.Z., Valderrabano, A., A DC-DC multilevel boost converter, IET Power Electronics, Vol. 3, Issue 1, pp.129-137, 2010.

[3] Mayo-Maldonado, J.C., Rosas-Caro, J.C., Salas-Cabrera, R., State space modeling and control of the DC-DC multilevel boost converter, IEEE 20th Int. Conf. on Electronics, Communications and Computer, pp.232 – 236, 2010.

[4] Mayo-Maldonado, J.C., Salas-Cabrera, R., Cisneros-Villegas, H., Gomez-Garcia, M., Salas-Cabrera, E.N., Castillo-Gutierrez, R., Ruiz-Martinez, O., Modeling and control of DCDC multilevel boost converter, IET Power Electronics, Vol. 4, Issue 6, pp.693-700, 2010.

[5] Schmidt, M., Advances in Computer Science and Engineering, IntechOpen, Croatia, pp.285-298, 2011.

[6] Mostafa, M., Mahrous, A., Mohamed, O., A Switch Inductor Multilevel Boost Converter, IEEE Int. Conf. on Power and Energy, pp.819-823, 2010.

[7] Hyun-Lark, D., A Zero-Voltage-Switching DC-DC converter with High Voltage Gain, IEEE transactions on power electronics, pp.1578-1586, 2011.

[8] Wuhua Li, Xiaodong Lv. Yan Deng, Jun Liu, Xiangning He, A Review of Non-Isolated High Step-Up DC/DC converters in Renewable Energy Application, IEEE Applied Power Electronics Conference and Exposition, pp.364-368. 2009.

Biography

Leardpan Piansangsan received his B.S. degree in Electrical Engineering from King Mongkut's University of Technology North Bangkok, in 2005; his M.S. degree in Engineering from the Mahasarakham University, Thailand, in 2013; He is presently working as a lecturer in the Department of Electrical Power Engineering, Pitchayabundit College. His current research interests include power converters and power generation.

Singthong Pattanasethanon received his Ph.D. (Energy Technology) from Mahasarakham University, Thailand. Presently, he is with the lecturer and researcher in the Department of Computer Engineering, Faculty of Engineering, Rajamangala University of Technology Thanyaburi. His scientific publications such as Empirical modeling and the forecasting illuminance/irradiance on horizontal plane using artificial neural network for all sky types at Mahasarakham, Thailand, Sky modeling daylight availability and illuminance/irradiance on horizontal plane for Mahasarakham, Thailand, and An Availability of Sky Luminance in Tropical Climate to Standard Voltages Conversion by Using Artificial Neural Network.