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Research Paper

COMPARISON OF N-STAGE CASCADE COCKCROFT-WALTON VOLTAGE MULTIPLIER APPLIED TO TRANSFORMER-LESS DC-DC BOOST CONVERTER

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This paper proposes a high step-up DC-DC converter based on Cockcroft-Walton (CW) voltage multiplier without using step up transformer. The low input DC voltage is boost up by boost inductor (Ls) in DC-DC converter. The n-stage CW-voltage multiplier is applying low input AC voltage to high output DC voltage. It provides continuous input current with low ripple, high voltage gain, reduced switching losses, low voltage stress on the switches, diodes and capacitors and also improving efficiency of the converter. Step-up dc-dc converters have been proposed to obtain high voltage ratios without extremely high duty cycle by using isolated transformers or coupled inductors. In order to obtain low input current ripple and high voltage ratio current-fed converters are used. Current-fed converters are more superior to the voltage-fed inverters. Finally the proposed converter is validated by MATLAB simulation for n-number of stages.

Keywords: Duty ratio, Performance parameters, Boost converter

INTRODUCTION

Non isolated dc-dc boost converter has found application in a variety of fields, owing to its ability to step-up low voltage dc input to high voltage dc-output. In recent years, with the development of power electronic devices and increase in its utility in renewable energy applications, boost converters have found its use due to high voltage gain, reduced voltage and current stress in the switching devices, improved efficiency and better dynamic response. Boost converters and derivative of its topologies have been implemented for PV systems, battery charging and in fuel cell applications [2-5]. The analysis of the behavior of the steady state and dynamic characteristics of a boost converter has also been under investigation [6].

Theoretically, the conventional boost dc-dc converter can provide a very high voltage gain

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by using an extremely high duty cycle. However, practically, parasitic elements associated with the inductor, capacitor, switch, and diode cannot be ignored, and their effects reduce the theoretical voltage gain. Up to now, many step-up dc-dc converters have been proposed to obtain high voltage ratios without extremely high duty cycle by using isolated transformers or coupled inductors. Among these high step-up dc-dc converters, voltage-fed type sustains high input current ripple. Thus, providing low input current ripple and high voltage ratio, current-fed converters are generally superior to their counterparts. A traditional current-fed push–pull converter was presented to provide the aforementioned merit. However, in order to achieve high voltage gain, the leakage inductance of the transformer is relatively increased due to the high number of winding turns. Consequently, the switch is burdened with high voltage spikes across the switch at the turn-off instant. Thus, higher voltage-rating switches are required.

BOOST CONVERTER

The conventional boost dc-dc converter can provide a very high voltage gain by using an extremely high duty cycle. However, practically, parasitic elements associated with the inductor, capacitor, switch, and diode cannot be ignored, and their effects reduce the theoretical voltage gain. Up to now, many step-up dc-dc converters have been proposed to obtain high voltage ratios without extremely high duty cycle by using isolated transformers or coupled inductors. Among these high step-up dc-dc converters, voltage-fed type sustains high input current ripple.

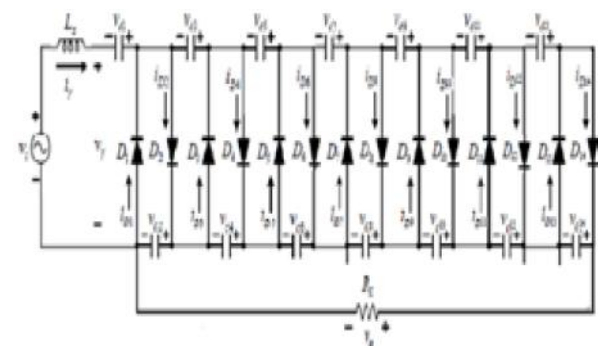
The system is operated with the high step-up converter based on the CW voltage multiplier with 5 or more stages. Replacing the step-up transformer with the boost-type structure, the proposed converter provides higher voltage ratio than that of the conventional CW voltage multiplier. Thus, the proposed converter is suitable for power conversion applications where high voltage gains are desired. Moreover, the proposed converter operates in Continuous Conduction Mode (CCM), so the switch stresses, the switching losses, and EMI noise can be reduced as well.

In recent years, extensive use of electrical equipment has imposed severe demands for electrical energy, and this trend is constantly growing. Consequently, researchers and governments worldwide have made efforts on renewable energy applications for mitigating natural energy consumption and environmental concerns. Among various renewable energy sources, the photovoltaic (PV) cell and fuel cell have been considered attractive choices. However, without extra arrangements, the output voltages generated from both of them are with rather low level.

Thus, a high STEPUP dc-dc converter is desired in the power conversion systems corresponding to these two energy sources. In addition to the mentioned applications, a high step-up dc-dc converter is also required by many industrial applications, such as high-intensity discharge lamp ballasts for automobile headlamps and battery backup systems for uninterruptible power supplies.

The proposed converter consists of one boost inductor L_s, four switches (S_{m1}, S_{m2}, S_{c1}, and S_{c2}), and one n-stage CW voltage multiplier. S_{m1}(S_{c1}) and S_{m2}(S_{c2}) operate in complementary mode, and the operating

Figure 1: 7-Stage Circuit



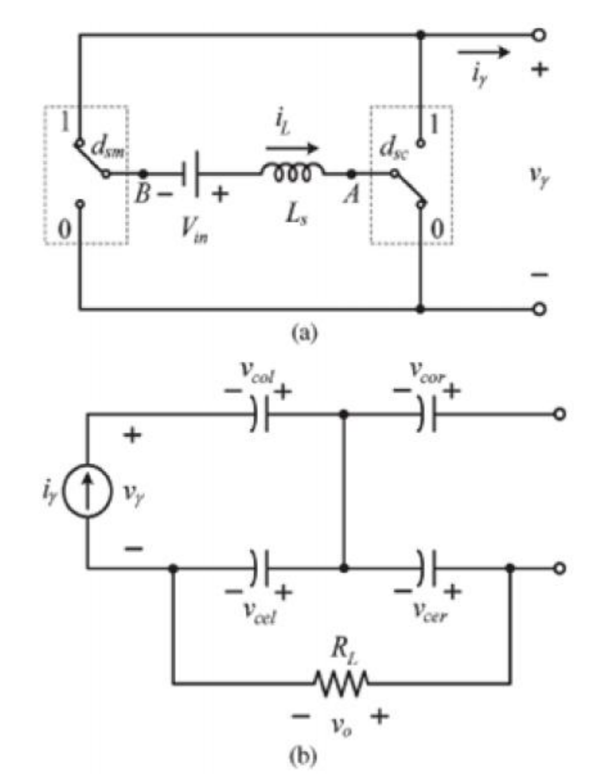
frequencies of *Sm*1 and *Sc*1 are defined as *fsm* and *fsc*, respectively. For convenience, fsm is denoted as modulation frequency, and fsc is denoted as alternating frequency. Theoretically, these two frequencies should be as high as possible so that smaller inductor and capacitors can be used in this circuit. In this paper, *fsm* is set much higher than fsc, and the output voltage is regulated by controlling the duty cycle of *Sm*1 and *Sm*2, while the output voltage ripple can be adjusted by *fsc*. As shown in Figure 1, the well-known CW voltage multiplier is constructed by a cascade of stages with each stage containing two capacitors and two diodes. In an n-stage CW voltage multiplier, there are N (=2n) capacitors and N diodes. For convenience, both capacitors and diodes are divided into odd group and even group according to their suffixes, as described in Figure 1.

STEADY STATE ANALYSIS OF BOOST CONVERTER

Figure 1 shows the proposed converter, which is supplied by a low-level dc source, such as battery, PV module, or fuel cell sources. The proposed converter consists of one boost converter.

In order to simplify the analysis of circuit operation, the proposed converter with a three-stage CW voltage multiplier, as shown in Figure 7, is used. Before analyzing, some assumptions are made as follows.

Figure 2: Equivalent Circuit of the Proposed Converter (a) Source-Side Part, (b) Load-Side Part



1. All of the circuit elements are ideal, and there is no power loss in the system.
2. When a high-frequency periodic alternating current is fed into the CW circuit and all of the capacitors in the CW voltage multiplier are sufficiently large, the voltage drop and ripple of each capacitor voltage can be ignored under a reasonable load condition. Thus, the voltages across all capacitors are equal, except the first capacitor whose voltage is one half of the others.
3. The proposed converter is operating in CCM and in the steady-state condition.

4. When the inductor transfers the storage energy to the CW circuit, only one of the diodes in the CW circuit will be conducted.

5. Some safe commutation states are ignored. According to the second assumption, each capacitor voltage in the CW voltage multiplier can be defined as:

$$v_{ck} = \begin{cases} V_c/2 & \text{for } k = 1 \\ V_c & \text{for } k = 2, 3, \ldots, N \end{cases}$$

where *vck* is the voltage of the k^{th} capacitor and *Vc* is the steady-state voltage of *vc*2 – *vcN*. For an n-stage CW voltage multiplier, the output voltage is equal to the total voltage of all even capacitors, which can be expressed as:

$$V_o = nV_c.$$

Each capacitor voltage in an n-stage CW voltage multiplier can also be expressed as:

$$v_{ck} = \begin{cases} V_o/2n & \text{for } k = 1 \\ V_o/n & \text{for } k = 2, 3, \ldots, N \end{cases}$$

where Vois the steady-state voltage of the output load side. Figure 8 shows the theoretical waveforms of the proposed converter, including switching signals, inductor current, *v*¥, *i*¥, and diode currents. According to the polarity of *i*¥, the operation of the proposed converter can be divided into two parts: positive conducting interval [t_0, t_1] for *i*¥ – 0 and negative conducting interval [t_1, t_2] for *i*¥ – 0.

Derivation of the Ideal Static Gain

It can be seen that the terminal voltage of the CW circuit *V*AB = 0 in states I and III, while in states II and IV, *V*AB = *Vo*/2*n*. The inductor current variation, during interval 0 < t < *DTsm*, can be represented as:

$$\Delta i_L = \frac{V_{\text{in}}}{L_s} DT_{\text{sm}}$$

where *Vin* is the input voltage, *Lsis* the boost inductor, and D is the duty cycle of the switch *Sm*1(*Sm*2) in the positive (negative) conducting interval over one modulation switching period *Tsm* = 1/*fsm*. Then, during interval *DTsm* < *t* < (1 – *D*)*Tsm*, the inductor current variation can be represented as:

$$\Delta i_L = \frac{V_{\text{in}} - V_o/2n}{L_s}(1 - D)T_{\text{sm}}$$

Under the steady-state condition, by the volt–second balance principle, the voltage gain of the proposed converter can be

$$M_V = \frac{V_o}{V_{\text{in}}} = \frac{2n}{1 - D}$$

where M_V represents the static voltage gain of the proposed converter. Moreover, the relationship between *i*¥ and *iL* can be obtained by |*i*¥|/*iL* = 1 – *D*. The relationship between voltage gain and duty cycle for the proposed converter under *n* = 1 – 8 and the classic boost dc-dc converter. Obviously, the proposed converter provides high voltage gain without extremely high duty cycle, while the classic boost dc-dc converter is operating at extremely high duty cycle.

SIMULATION RESULTS

Table 1: Comparison of Performance Parameters of 3-Stage and 7-Stage Boost Converter

Parameters	Ratings	
	3-STAGE	7-STAGE
Input DC voltage, Vin	40-55 V	
Output Voltage, Vo	430 KV	680KV
Modulation frequency, FSM	60 kHz	
Alternating frequency, FSC	1 kHz	
Resistive load, RL	1 KΩ	
Boost inductor, Ls	1.5 mH	
Capacitors	470 μF	

Figure 3: 7-Stage Boost Converter Output Voltage Waveform

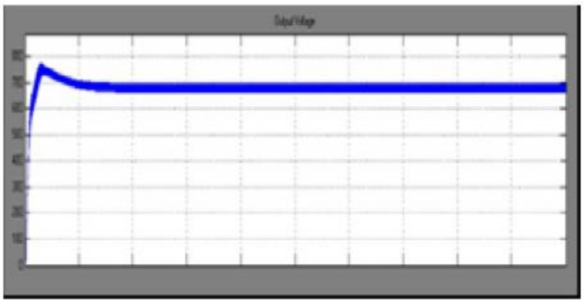
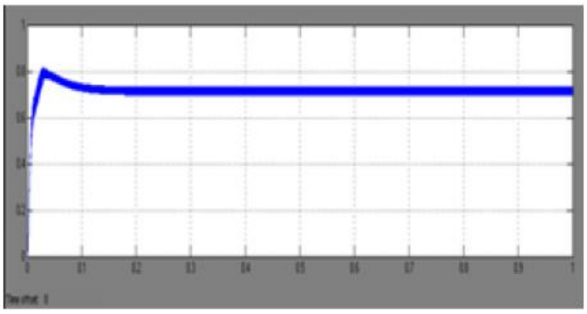


Figure 4: 7-Stage Boost Converter Output Current Waveform



CONCLUSION

In this paper, a high step-up DC-DC converter based on CW voltage multiplier without a line or high-frequency step-up transformer was presented to obtain a high voltage gain. Since the voltage stress on the active switches, diodes, and capacitors is not affected by the number of cascaded stages, power components with same voltage ratings can be selected. The mathematical modeling, circuit operation, design considerations, and control strategy were discussed. The control strategy of the proposed converter can be easily implemented with a commercial average-current-control and continuous current mode with adding a programmed. The proposed control strategy employs two independent frequencies, one of which operates at high frequency to minimize the size of the inductor, while the other one operates at relatively low frequency according to the desired output voltage ripple. Finally, the simulation and experimental results proved the validity of theoretical analysis and the feasibility of the proposed converter. Thus the design, simulation and analysis of proposed DC-DC boost converter with three and seven-stage Cockcroft Walton voltage multiplier was done.

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