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A Novel High Step-Up DC-DC Converter for Photovoltaic Applications

Annop Nakpin[a], Sudarat Khwan-on[a]*

[a]School of Electrical Engineering, Suranaree University of Technology, Nakhon Ratchasima, Thailand, 30000

Abstract

This paper proposes a new topology of a high step-up dc-dc converter for photovoltaic system applications. The proposed converter can boost up the low input voltage, about 20V, generated from the PV array to the high output voltage level of approximately 400V. The proposed converter employs only one power switch to achieve a high step-up voltage conversion ratio, approximately 20 times, without the extremely large duty cycle. The operating principles and steady-stage analyses of continuous conduction mode are described in detail. The relationship between the step-up voltage ratio and the duty cycle of the proposed converter is analyzed. The simulation and experimental results are shown to demonstrate the effectiveness of the proposed high step-up single-switch dc-dc converter for low-input and high-output voltage systems.

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Keywords: DC-DC converter; High step-up voltage gain; Single switch; Photovoltaic system

1. Introduction

Nowadays, renewable energy sources such as photovoltaic (PV) arrays and wind turbine generators, have received increasingly attentions due to energy shortage and environmental contamination [1]. Such renewable energy systems typically generate low voltage output. Therefore, high step-up dc-dc converters are widely employed in many renewable energy system applications. The output voltage generated from a single PV panel is about 15V to 40V [2].

* Corresponding author. Tel.: +66-44-224-400; fax: +66-44-224-601.
E-mail address: sudarat_kh@sut.ac.th

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This voltage level is not sufficient for the dc-link voltage (400V) of a single-phase inverter to generate the ac power with 220V grid voltage [3]. In order to boost the low output voltage up to the higher level, a conventional boost converter is commonly used because of its simple structure and control. Unfortunately, it cannot achieve a high step-up conversion with high efficiency due to the extreme duty cycle operating limitations. A number of modified high step-up converter topologies have been proposed in order to increase the voltage conversion ratio [4]. The modified SEPIC converter with the combination of an auto-transformer and the coupled inductors is introduced to photovoltaic application in order to increase the voltage gain of the converter [5]. However, the converter efficiency is quite low because of the leakage inductance energy stored in the auto-transformer and the coupled inductors [6].

In this paper the high step-up dc-dc converter with a single power switch is proposed for photovoltaic system applications. The proposed high step-up boost converter topology is presented in the following section. The operating principle of the proposed converter under continuous conduction mode (CCM) is described in detail. A 500W laboratory prototype of the proposed converter was implemented. Simulation and experimental results are shown in order to illustrate the effectiveness of the proposed converter to achieve a much higher step-up conversion ratio compared with that of the conventional boost converter.

2. High Step-Up DC-DC Converter Topology

A novel high step-up dc-dc converter topology is proposed as shown in Fig. 1. In order to achieve the high step-up conversion ratio, the proposed converter configuration is basically based on the combination of the voltage multiplier module in the first stage and the conventional boost converter in the second stage. As it can be seen, the proposed converter consists of only one active power switch, the input inductor L_1, the output diode D_O, the filter capacitor C_O, the inductor L_2, the dc-link capacitor C_3. The voltage multiplier cell is configured from two identical capacitors, C_1 and C_2, and three diodes, D_1, D_2 and D_3. The blocking diode D_4 is between the voltage multiplier module and the boost converter.

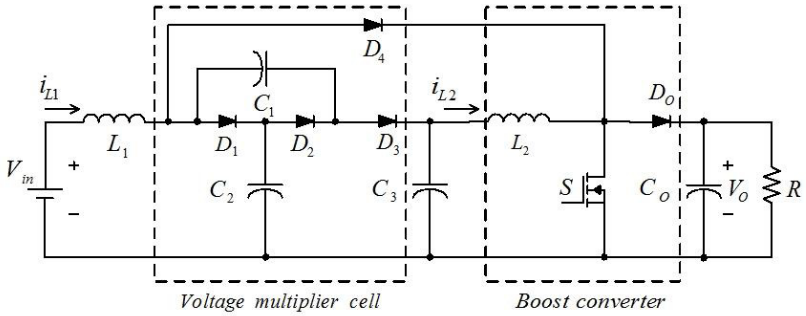

Fig. 1 The proposed high step-up dc-dc converter configuration

The operation of the converter during one switching period can be basically divided into four modes. The operating principle of the proposed converter can be described briefly as follows:

Mode 1: the switch S and the diode D_3 are turned on. The remaining diodes are all off. V_{in} and C_1 deliver energy to L_1 and L_2. Thus, during this operation mode both i_{L1} and i_{L2} increase linearly to store energy in L_1 and L_2, respectively. The capacitor C_3 is charged. The output power is supplied from capacitor C_O.

Mode 2: the switch S remains conducting and diode D_3 is off. The diodes D_1, D_4 and D_O remain reversely biased but D_2 is forward biased. The energy stored in C_3 is released through L_2. The capacitors C_1 and C_2 are now in charging and discharging stages, respectively.

Mode 3: the switch S is turned off but D_2 becomes reversely biased. The diodes D_1, D_3 and D_O are in forward-biased state. The inductor L_1 releases energy to C_2 while C_1 delivers energy to L_2 through D_3. In addition, the output filter capacitor C_O is supplied from the energy stored in L_2 through D_O.

Mode 4: the switch S is still in turned-off state and D_1 becomes reversely biased. The diodes D_3 and D_O remain in forward-biased state. The energy stored in L_1 and C_1 is transferred the boost converter side charging the output capacitor filter C_O via diodes D_3 and D_O.

In order to consider the performance of the proposed high step-up dc-dc converter, the voltage step-up conversion ratio (M) under the steady-state operating condition is analyzed. The transient characteristics of circuitry are disregarded to simplify the proposed converter performance analysis. As can be seen in Fig. 1, the proposed converter operates with the incorporation of the voltage multiplier module and the conventional boost converter in the first and second stages, respectively. Therefore, the voltage gain of the proposed converter can be expressed as

$$M = \frac{V_o}{V_{in}} = \frac{2}{(1-D)^2} \tag{1}$$

As can be seen in (1), it confirms that the proposed converter provides a high step-up voltage-conversion ratio without adopting an extremely large duty cycle, *D*. The voltage conversion ratio characteristic of the proposed converter as a function of duty cycle is shown in Fig. 2(a). As can be seen, a much higher voltage conversion ratio of the proposed converter can be achieved than that of the other two boost converters over a range of duty cycle. In addition, it is clear that the proposed converter can provide a high voltage gain of 20 times without the extreme duty cycle. Fig. 2(b) illustrates the proposed converter efficiency curve as a function of the output load power. It can be seen that the efficiency of the proposed converter is approximately 90%.

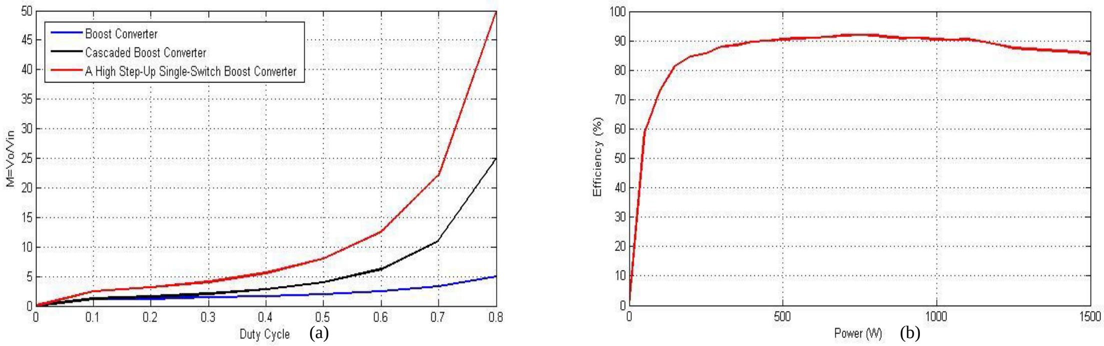

Fig. 2 Performances of the proposed high step-up dc-dc converter (a) conversion ratio characteristic (b) efficiency

3. Experimental and Simulation Results

To verify the effectiveness of the proposed high step-up dc-dc converter, simulation results have been presented using MATLAB SIMULINK. In addition, a phototype of the proposed converter with 20V-input voltage, 400V-output voltage and output power of 500 W was implemented, as shown in Fig. 3, for performance verification. The component parameters of the proposed converter shown in Fig. 1 are designed as L_1, L_2 = 15mH, C_1 and C_2 = 100μF, C_3 = 150μF, C_O = 100μF and R = 500Ω. The power MOSFET, namely, IXFX80N60P3, and ultrafast-recovery diodes, namely, RURP3060, are selected. The switching frequency is 20kHz. A TMS320F28335 DSP board is employed to generate the switching signal to the power switch. The input voltage of 10V is fundamentally tested not only to verify the theoretical analysis and simulation results but also to avoid the negative impacts on the proposed converter due to the large transient overcurrent under open-loop operating conditions. For future work the input voltage of 20V will be supplied to the proposed converter operating with an appropriate controller in order to obtain the desired level of the step-up output voltage.

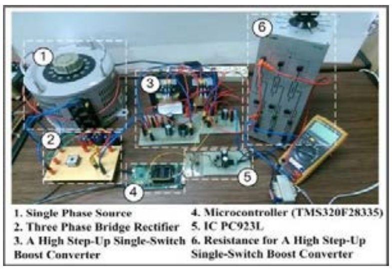

Fig. 3 A 500-W prototype of the proposed high step-up dc-dc converter

Fig. 4 shows the experimental and simulation results of switching signal and output voltage waveforms obtained from the proposed converter with duty cycle of 0.3. The simulated output voltage is about 40V while the experimental one is about 40.5V. It is clear that the obtained results are in a good agreement. Similarly, the tested- and simulated output voltages are approximately 80V, as shown in Fig. 5, when duty cycle is 0.5. As it can be seen, the output voltage waveforms under given duty cycles agreed with the voltage ratio characteristic shown in Fig. 2. Therefore, the proposed converter can provide a high step-up conversion ratio without an extreme large duty cycle.

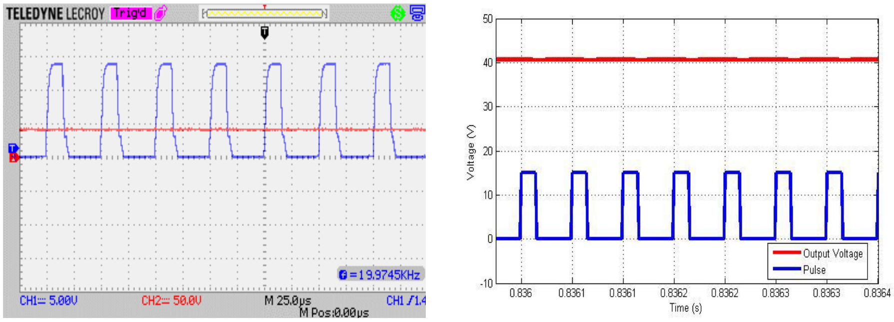

Fig.4 Output voltage and switching signal obtained from experiment and simulation when $D = 0.3$

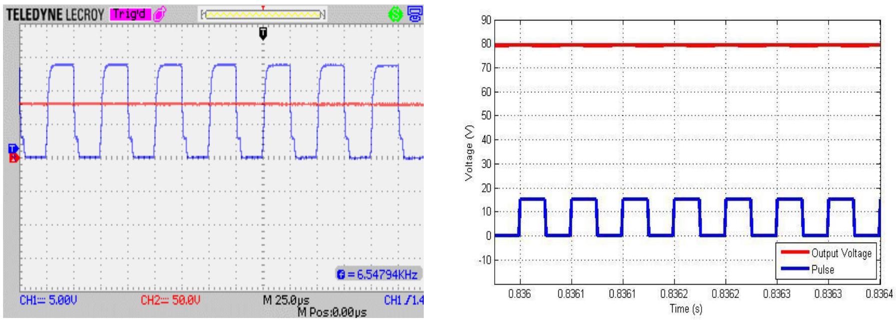

Fig.5 Output voltage and switching signal obtained from experiment and simulation when $D = 0.5$

4. Conclusion

This paper has presented a novel high step-up dc-dc converter, which can step-up a low input voltage to a high level without an extremely large duty cycle. Thus, the proposed converter is suitable for photovoltaic system applications or other renewable energy applications that need high step-up voltage conversion ratio. The proposed converter topology is based on the incorporation of the voltage multiplier module and the conventional boost converter in order to achieve a high voltage gain. The operation principle and steady analysis as well as a comparison with other boost converters are presented. Finally, a 500-W prototype with 20V input and 400V output is built for performance verification of the proposed converter. Simulation and experimental results are in a good agreement, verifying the effectiveness of the proposed converter.

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