

A High Step-Up Boost-Flyback Converter with Voltage Multiplier Module for Photovoltaic System

Atul V S¹, Soumya Simon²

P.G. Student, Department of Electrical and Electronics Engineering, FISAT, Angamaly, Kerala, India¹

Assistant Professor, Department of Electrical and Electronics Engineering, FISAT, Angamaly, Kerala, India²

ABSTRACT: This paper presents a high step up boost-flyback converter for a front-end photovoltaic system. Through a voltage multiplier module, an asymmetrical interleaved high step-up converter obtains high step-up gain without operating at an extreme duty ratio. The conventional boost converter and coupled inductors are used to compose voltage multiplier module by integrating an extra conventional boost converter to achieve considerably higher voltage conversion ratio. The two phase configuration not only constrains the input current ripple but also reduce the current stress through each power switch, which decrease the conduction losses of MOSFETs. The converter works as an active clamp circuit, which alleviates large voltage spike across the power switches, thus low voltage rated MOSFETs can be adopted for reduction of conduction losses and cost. The system efficiency improves because the energy stored in the leakage inductors are recycled to the output terminal.

KEYWORDS: Renewable energy system, Boost-Flyback converter, High Step-Up, Photovoltaic System, Voltage Multiplier Module.

I. INTRODUCTION

Nowadays renewable sources of energy are used in worldwide, because of energy shortage and environmental contamination. The high step-up DC-DC converter is widely used in the renewable systems because they produce low voltage output. Among the renewable energy resources the photovoltaic systems having a greater hand in future energy production. The photovoltaic systems transforms light energy in to electrical energy and convert low voltage into high voltage via step-up converter which can convert energy in to electricity using grid-by-grid inverter or store energy into battery set [1]-[2]. A typical photovoltaic system consists of a solar module, a high step-up converter, a charge-discharge controller, a battery set, and an inverter. The high step-up converter performs importantly among the system because the system requires a sufficiently high step-up conversion.

The conventional step-up converters, such as the boost converter and flyback converter, cannot achieve a high step-up conversion with high efficiency because of the resistances of elements or leakage inductance. Thus, a modified boost-flyback converter was proposed [3]-[5]. The conventional step-up converters with a single switch are unsuitable for high-power applications given an input large current ripple, which increases conduction losses. Thus, numerous interleaved structures and some asymmetrical interleaved structures are extensively used. This study also presents an asymmetrical interleaved converter for a high step-up and high-power application [6]. In this paper, an asymmetrical interleaved high step-up converter that combines the advantages of the aforementioned converters is proposed, which combined the advantages of both. In the voltage multiplier module of the proposed converter, the turns ratio of coupled inductors can be designed to extend voltage gain, and a voltage-lift capacitor offers an extra voltage conversion ratio. The advantages of the proposed converter are as follows:

- 1) The converter achieves the high step-up voltage gain that renewable energy systems require;

- 2) Leakage energy is recycled and sent to the output terminal, and alleviates large voltage spikes on the main switch;
- 3) The main switch voltage stress of the converter is substantially lower than that of the output voltage;
- 4) Low cost and high efficiency are achieved.

This Paper is organized as follows. Section II describes operating principle and mode of operation of Boost-Flyback converter, section III presents simulation results Finally, Section V presents conclusion.

II. OPERATING PRINCIPLE

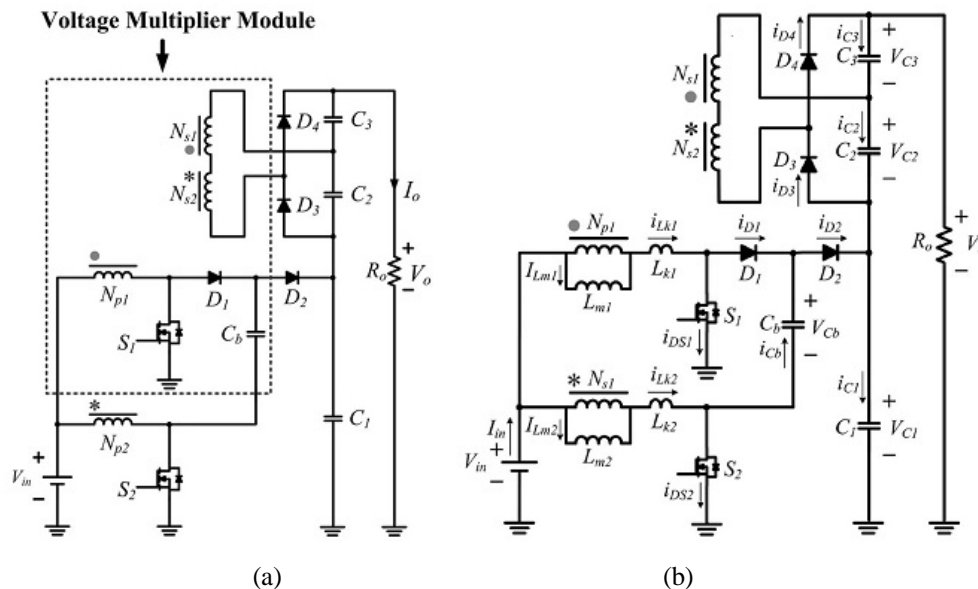


Fig.1 (a) Proposed high step-up converter with a voltage multiplier module

(b) Equivalent circuit of the proposed converter.

The proposed high step-up converter with voltage multiplier module is shown in Fig. 1(a). A conventional boost converter and two coupled inductors are located in the voltage multiplier module, which is stacked on a boost converter to form an asymmetrical interleaved structure. Primary windings of the coupled inductors with N_p turns are employed to decrease input current ripple, and secondary windings of the coupled inductors with N_s turns are connected in series to extend voltage gain. The turns ratios of the coupled inductors are the same. The coupling references of the inductors are denoted by “.” and “*” in Fig.1.

The equivalent circuit of the proposed converter is shown in Fig. 1(b), where L_{m1} and L_{m2} are the magnetizing inductors, L_{k1} and L_{k2} represent the leakage inductors, S_1 and S_2 denote the power switches, C_b is the voltage-lift capacitor, and n is defined as a turns ratio N_s/N_p . The proposed converter operates in continuous conduction mode (CCM), and the duty cycles of the power switches during steady operation are interleaved with a 180° phase shift; the duty cycles are greater than 0.

III. MODE OF OPERATION

MODE-1 [t_0 - t_1]: During this mode at time $t=t_0$, the power switches S_1 and S_2 turned ON hence all diodes are reverse biased. Magnetizing inductors L_{m1} , L_{m2} and leakage inductors L_{k1} L_{k2} linearly charged by V_{in} .

MODE-2 [t_1 - t_2]: During this mode at time $t=t_1$, the power switch S_2 OFF hence the Diodes D_2 and D_4 turned on Energy stored in L_{m2} transferred to 2^0 and charge C_3 , L_{m2} , L_{k2} , C_b , V_{in} release energy to C_1 via D_2 This extend the voltage in C_1 .

MODE-3 [t_2 - t_3]: During this mode at time $t=t_2$ D_2 automatically switched off because L_{k2} completely released to C_1 . The energy stored in L_{m2} transferred to 2^0 and charge C_3 via D_4 .

MODE-4 [t_3 - t_4]: During this mode at time $t=t_3$ the power switches S_1 and S_2 turned ON hence all diodes are reverse biased. Magnetizing inductors L_{m1} , L_{m2} and leakage inductors L_{k1} L_{k2} linearly charged by V_{in} . it is same as mode 1

MODE-5 [t_4 - t_5]: During this mode at time $t=t_4$, the power switch S_1 OFF hence D_1 , D_3 turned on Energy stored in L_{m1} transferred to 2^0 and charge C_2 L_{m1} , L_{k1} , V_{in} release energy to C_b via D_1 , which stores extra energy in C_b .

MODE-6 [t_5 - t_0]: During this mode at time $t=t_5$. The D_1 automatically switched off because L_{k1} completely released to C_b Energy stored in L_{m1} transferred to 2^0 and charge C_2 via D_3 until t_0 .

The key steady waveforms in one switching period of the proposed converter contain six modes, which are depicted in Fig. 2, and Fig. 3 shows the topological stages of the circuit.

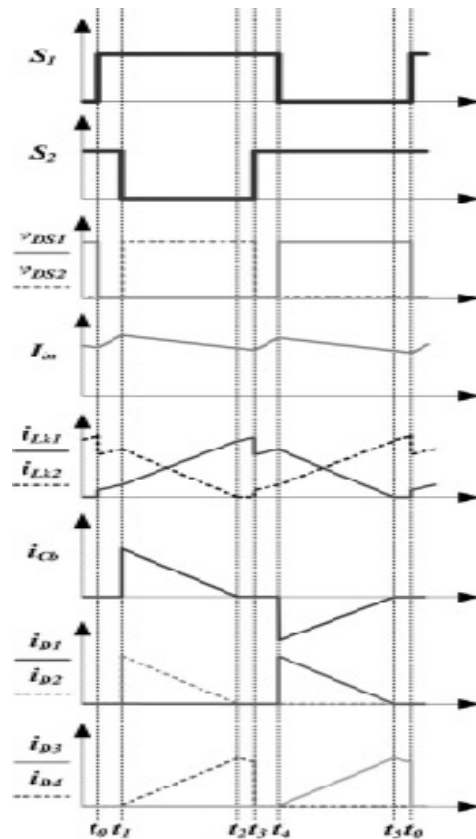


Fig 2: Steady waveforms of the proposed converter at CCM.

Some assumptions are made for the design of the model. All components are assumed to be ideal, L_{k1} and L_{k2} are neglected, V_{C1}, V_{C2}, V_{Cb} are considered to be constant because of infinitely large capacitance. The design formulas are given below,

$$V_{CB} = \frac{1}{1-D} V_{in} = \frac{1}{1-0.6} * 40 = 100V \tag{1}$$

$$V_{C2} = \frac{2}{1-D} V_{in} = \frac{2}{1-0.6} * 40 = 200V \tag{2}$$

$$V_{C1} = \frac{n}{1-D} V_{in} = \frac{1}{1-0.6} * 40 = 100V \tag{3}$$

$$V_{C3} = \frac{n}{1-D} V_{in} = \frac{1}{1-0.6} * 40 = 100V \tag{4}$$

$$V_0 = V_{C1} + V_{C2} + V_{C3} = 200 + 100 + 100 = 400V \tag{5}$$

$$V_{Gain} = \frac{2n+2}{1-D} = \frac{V_0}{V_{in}} = \frac{2*0.6+2}{1-0.6} = \frac{400}{40} = 10 \tag{6}$$

$$C_1 (boost) = \frac{DT SVD}{RAVO} = \frac{400 * 0.6 * (\frac{1}{10-100})}{160 * 0.3} = 12.5mF \tag{7}$$

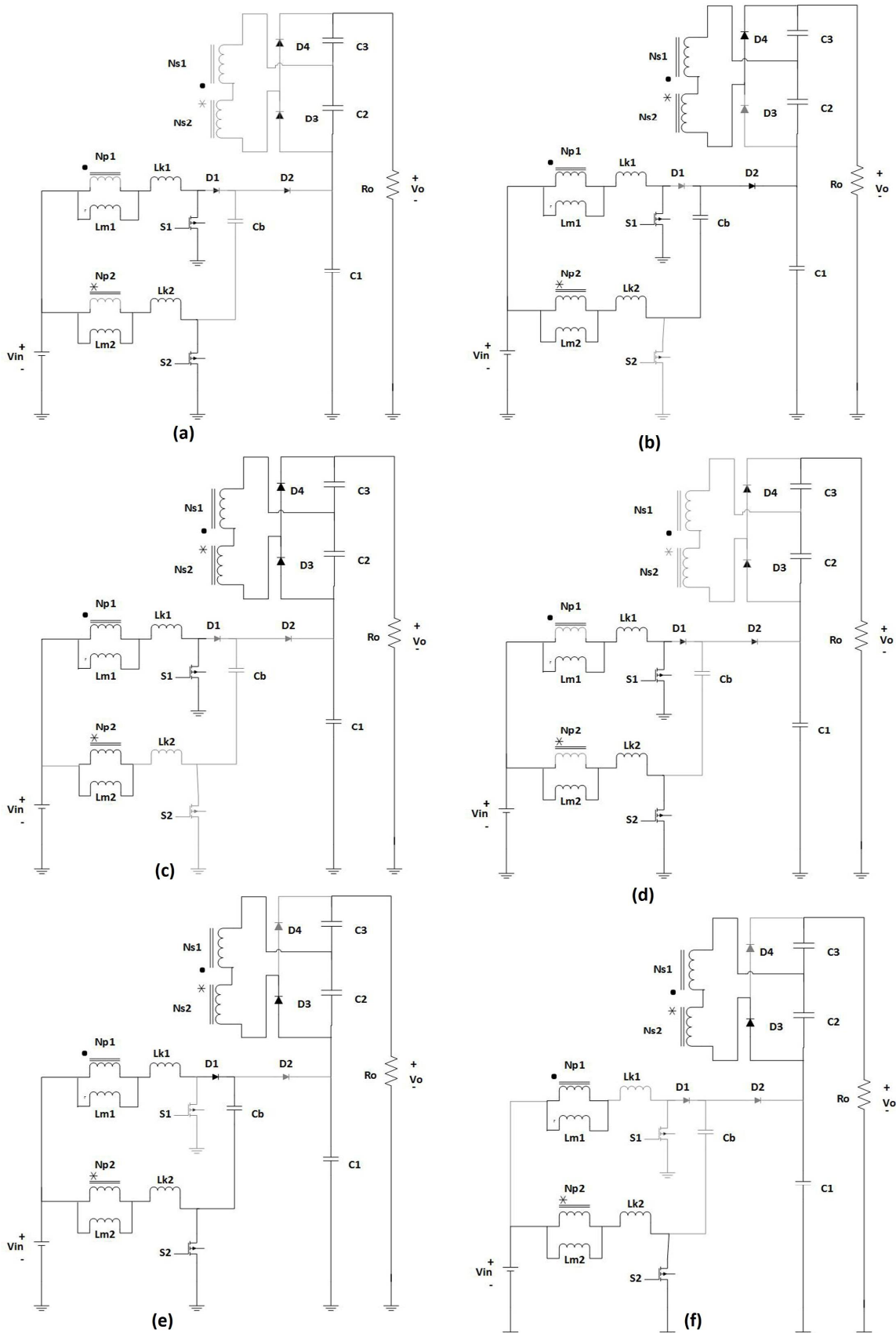


Fig 3: Operating modes of the proposed converter. (a) Mode 1 $[t_0, t_1]$. (b) Mode 2 $[t_1, t_2]$. (c) Mode 3 $[t_2, t_3]$. (d) Mode 4 $[t_3, t_4]$. (e) Mode 5 $[t_4, t_5]$. (f) Mode 6 $[t_5, t_0]$.

A prototype of the proposed high step-up converter with a 40-V input voltage, 320-V output voltage, and maximum outputpower of 1 kW is tested. The switching frequency is 40 kHz. The values of the primary leakage inductors of the

coupled inductors are set as close as possible for current sharing performance. Due to the performances of high step-up gain, the turns ratio can be set 1 for the prototype circuit with a 40V input voltage, 320V output to reduce cost, volume, and conduction loss of winding. Thus, the copper resistances which affect efficiency much can be decreased. The value of magnetizing inductors L_{m1} and L_{m2} can be design based on the equation of boundary operating condition, which is derived from ,

$$L_{m(\text{critical})} = \frac{R_0 \cdot D(1-D)^2}{2(n+1)(2n+2)f_s} = \frac{160 \cdot 0.6(1-0.6)^2}{2(1+1)(2 \cdot 1+2) \cdot 40 \cdot 10^3} = 24 \mu\text{H} \tag{8}$$

Where L_m (critical) is the value of magnetizing inductors at the boundary operating condition, f_s is the switching frequency, and R_o is the load. How to suppress the voltage ripple on the voltage lift capacitor C_b to an acceptable value is the main consideration. The equation versus the voltage ripple and the output power or output current can be derived by ,

$$C_b = \frac{P_0}{V_0 f_s \Delta V_{C_b}} = \frac{1 \cdot 10^3}{400 \cdot 40 \cdot 10^3 \cdot 0.3} = 20 \text{ mF} \tag{9}$$

Where P_o is the output power, V_o is the output voltage, f_s is the switching frequency, and ΔV_{C_b} is the voltage ripple on the voltage-lift capacitor C_b .

IV. SIMULATION RESULTS

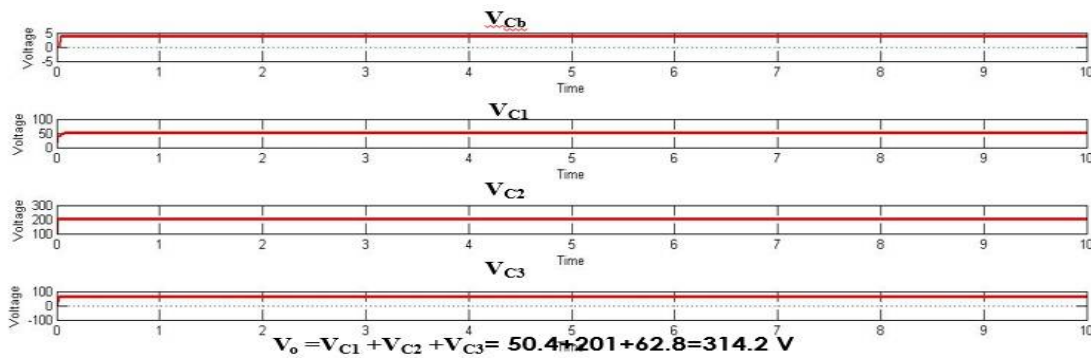


Fig 4: Simulation results of volatage across cappacitors C_1, C_2 and C_3

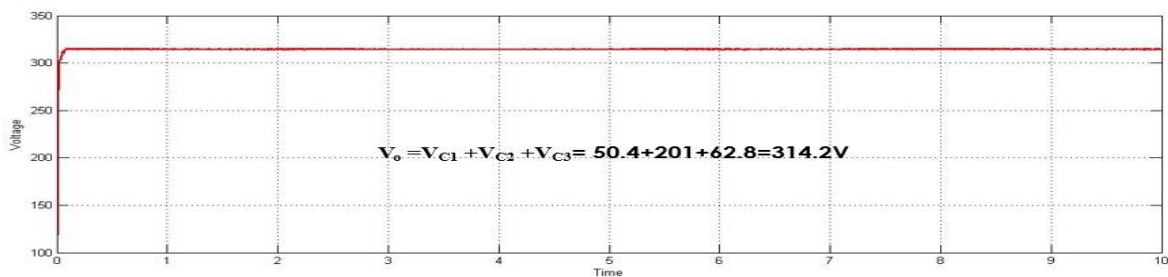


Fig 5: Output voltage across load

V. CONCLUSION

The high step-up boost-flyback converter with voltage multiplier module for efficient PV system with different topologies and simulation results are presented in this paper. The proposed converter has been successfully implemented in an efficiently high step-up conversion without an extreme duty ratio and number of turns ratios through voltage multiplier module. The voltage stress over power switches are reduced by interleaved PWM. The leakage energy is recycled through capacitor C_b . Thus the proposed converter is suitable for PV systems or other renewable energy applications that need high step-up high power conversion. full-load efficiency is 96.1% at $P_o = 1000$ W, and the highest efficiency is 96.8% at $P_o = 400$ W. Thus, the proposed converter is suitable for PV systems or other renewable energy applications that need high step-up high-power energy conversion.

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