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

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Abstract— A high step up converter, which is suitable for producing DC output renewable energy system, is proposed in this paper. A conventional interleaved boost converter obtains high step up gain without operating at extreme duty ratio through a voltage multiplier module composed of switched capacitors and coupled inductors. In addition leakage energy is recycled to output terminal, due to lossless passive clamp performance. Hence, large voltage spikes across the main switches are alleviated, and the efficiency is improved. Even the low voltage stress makes the low voltage rated MOSFETs be adopted for reductions of conduction losses and cost. Finally, the simulation circuit with 24V input voltage 600V output voltage and hardware is designed with 12V input voltage is operated to verify its performance. The highest efficiency is 97.5%.

Key words: Voltage multiplier, coupled inductor, photovoltaic system

I. INTRODUCTION

Nowadays renewable is increasingly valued and employed worldwide because of energy shortage and environmental contamination. Renewable energy systems generate low voltage output, and thus, high step up DC/DC converters have been widely employed in many renewable energy application such as fuel cell and photovoltaic systems(3). Such systems provide electrical energy by transforming energy from renewable sources and convert energy into electricity using a grid by grid inverter or DC micro grid.

Figure 1 shows typical renewable energy system that consists of renewable energy sources, a step up converter. A high step up converter is an important part in the system because such a system requires a sufficiently high step up conversion with high efficiency.

Theoretically, boost converter and fly back converter cannot achieve a high step up conversion with efficiency because of resistance of element or leakage inductance; also, the voltage stresses are large(1). The high step up single switch converter is unsuitable to operate at heavy load given a large input current ripple, which increases conduction losses. For high power application and power factor correction, the conventional boost converter is an excellent candidate(2).

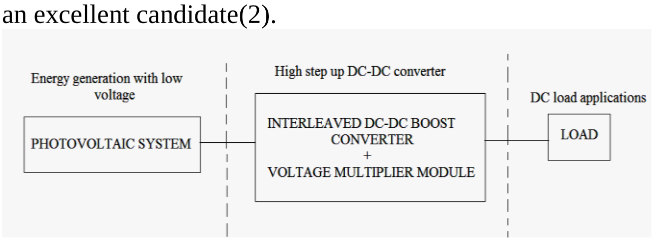

Fig. 1: Block Diagram Of High Step Up Interleaved DC-DC Boost Converter With Voltage Multiplier Module For Photovoltaic System

Unfortunately, the step up gain is limited, and voltage stresses on semiconductor components are equal to output voltage. Hence, based on aforementioned considerations, modifying a conventional interleaved boost converter for high step-up and high power application is suitable approach. To integrate switched capacitors into interleaved boost converter may make voltage gain reduplicate but no employment of coupled inductors causes the step-up voltage gain to be limited(4),(5).

To integrate only coupled inductors into an interleaved boost converter may make voltage gain higher and adjustable, but no employment of switched capacitors causes the step-up voltage gain to be ordinary(6),(7).Thus, the synchronous employment of coupled inductors and switched capacitors is better concept. The proposed converter is a conventional interleaved boost converter integrated with a voltage multiplier module which is composed of switched capacitors and coupled inductors. The coupled inductors offer high step-up gain and switched capacitors offer extra voltage conversion ratio. In addition the energy stored in magnetizing inductor will transfer via three respective paths, when one of the switches turns off.

The advantages of the proposed converter are as follows:

(1) The proposed converter is characterized by low input current ripple and low conduction losses, which increases the lifetime of renewable energy sources and makes it suitable for high power applications.
(2) The leakage energy is recycled to output terminal due to, the lossless passive clamp performance. Hence large voltage spikes across the main switches are alleviated, and efficiency is improved.
(3) By employment of the low-voltage-rated power switch with low R_{DS} (ON), low cost and high efficiency are achieved.
(4) The inherent configuration of proposed converter makes some diodes decrease conduction losses and alleviate diode reverse recovery losses.

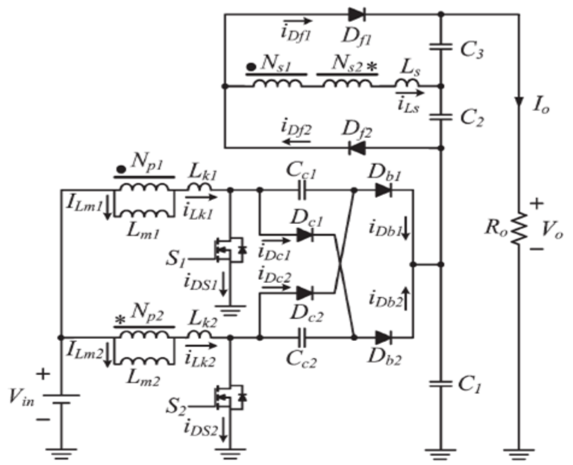

Fig. 2: Circuit Configuration of High Step Up Interleaved DC-DC Boost Converter With Voltage Multiplier Module

II. OPERATING PRINCIPLE

The proposed high step-up interleaved DC-DC boost converter with voltage multiplier module which consists of coupled inductors and switched capacitors. When the switches turn off by turn, the phase whose switch is in OFF state performs as a fly back converter, and the other phase whose switch is in ON state performs as a forward converter.Primary windings of the coupled inductors with Np turns are employed to decrease input current ripple, and the secondary windings of coupled inductors with Ns turns are connected in series to extend the voltage gain. The turns ratio of the coupled inductors are same.

The equivalent circuit of the proposed converter is shown in fig 3, where Lm1and Lm2 are the magnetizing inductors; $L_{k1}$and L_{k2} represent the leakage inductors; Ls represents the series leakage inductors in secondary side S_1 and S_2 are the power switches; Cc1and Cc2 are the switched capacitors; and C_1, C_2 and C_3 are output capacitors.D_{c1} and D_{c2} are clamp diodes, D_{b1} and D_{b2} represent the output diodes for boost operation with switched capacitors, The proposed converter operation contains eight modes, which are depicted in fig3 shows the topological stages of the circuit.

*MODE 1[t0,t1]:*At t=t0, S_2 remains in ON state and S_1 begins to turn on. The diodes .D_{c1}, D_{c2}, D_{b1}, D_{b2} and D_{f1} are reverse biased. Ls quickly release the stored energy to output terminal via D_{f2}, and current through Ls decreases to zero. Thus Lm1 still transfers the energy to the secondary side of the coupled inductors. The current through L_{k1} increases linearly and L_{k2} decreases linearly.

MODE 2[t1,t2]: At t=t1, both switches S_1 and S_2 remain in ON state, and all diodes are reverse biased. The current through L_{k1} and L_{k2} are increased linearly due to charging by Vin.

*DE 3[t2,t3]:*At t=t2, S_1 remains in ON state and S_2 begins to turn off. The diodes D_{c1}, D_{b1} and D_{f2} are reverse biased. The input voltage source L_{m2}, $L_{k2}$and C_{c2} release energy to output terminal. Thus, Vc1 obtains a double output voltage of boost converter.

*MODE 4[t3,t4]:*At t=t3, the current i_{Dc2} has naturally decreased to zero due to magnetizing current distribution , and hence , diode reverse recovery losses are alleviated and conduction losses are decreased. Both power switches and all diodes remain in previous state except the clamp diode D_{c2}.

*MODE 5[t4,t5]:*At t=t4, S_1 remains in ON state and S_2 begins to turn on. The diodes D_{c1}, D_{c2}, D_{b1}, D_{b2} and D_{f2} are reverse biased and Ls quickly release the stored energy to output terminal via D_{f1} and the magnetizing inductor L_{m2} still transfers the energy to secondary side of coupled inductor. The current through L_{k2} increases linearly and L_{k1} decreases linearly.

MODE 6[t5,t6]: At t=t5, both of the power switches S_1 and S_2 remains in ON state, and all diodes are reverse biased. Both current through L_{k1} and L_{k2} are increased linearly due to charging by Vin.

*MODE 7[t6,t7]:*At t=t6, S_2 remains in ON state and S_1 begins to turn off. The diodes D_{c2}, D_{b2} and D_{f1} are reverse biased. The energy stored in L_{m1} transfers to the secondary side of coupled inductor. The input voltage source, L_{m1}, $L_{k1}$and C_{c1} release the energy to output terminal and V_{c1} obtains double output voltage of boost converter.

*MODE 8[t7,t8]:*At t=t7, the current i_{Dc1} has naturally decreased to zero due to magnetizing current distribution and hence, diode reverse recovery losses are alleviated and conduction losses are decreased. Both power switches and all diodes remain in previous state except the clamp diode D_{c1}.

III. VOLTAGE GAIN

The voltage on clamp capacitor Cc can be regarded as an output voltage of boost converter[8]; thus, voltage Vcc can be derived from

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

Voltage Vc1 can obtain a double output voltage of boost converter,when one of the switches turn off. That is derived

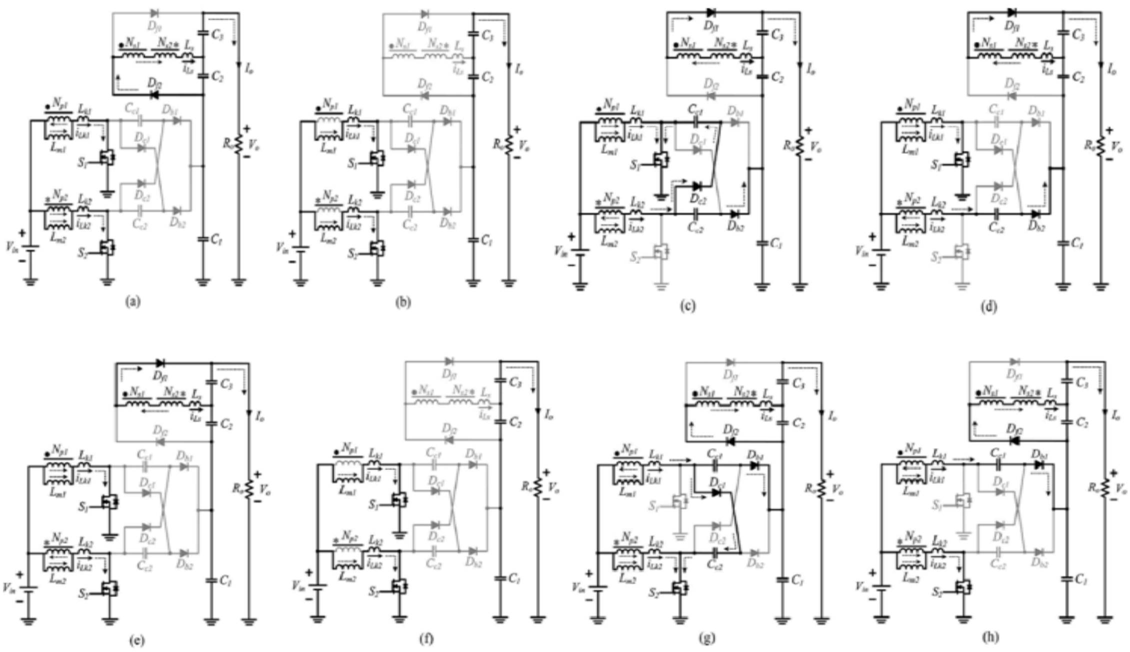

Fig. 3: Operating Modes Of The Proposed Converter. (A) Mode I [*To*, *T*1]. (B) Mode II [*T*1, *T*2]. (C) Mode III [*T*2,*T*3].

(D) Mode IV [*T*3, *T*4]. (E) Mode V [*T*4, *T*5]. (F) Mode VI [*T*5, *T*6]. (G) Mode VII [*T*6, *T*7]. (H) Mode VIII [*T*7, *T*8].

From the equation given below,

$$V_{C1}= \frac{1}{1-D} V_{in} + V_{Cc}= \frac{2}{1-D}V_{in} \qquad (2)$$

Due to energy transformation from the primary side, the output filter capacitors C_2 and C_3 are charged. When S_2 is in ON state and S_1 is in OFF state, Vc2 is equal to the induced output voltage of Ns1 and induced voltage of Ns2, and when S_1 is in ON state and S_2 is in OFF state, Vc3 is equal to induced voltage of Ns1 plus induced voltage of Ns2. Thus, voltages Vc2 and Vc3 can be derived from

$$VC2 = VC3 = n\,,Vin\ (1+\frac{D}{1-D}) = \frac{n}{1-D}Vin \qquad (3)$$

The output voltage can be derived from

$$Vo = VC1+ VC2 + VC3 =\frac{2n+2}{1-D}Vin \qquad (4)$$

In addition, the voltage gain of proposed converter is

$$\frac{Vo}{Vin} = \frac{2n+2}{1-D} \qquad (5)$$

Equation (5) confirms that proposed converter has a high step up voltage gain without an extreme duty cycle. When the duty cycle is merely 0.6, the voltage gain reaches ten at a turns ratio n of one; the voltage gain reaches 30 at a turn ratio n of five.

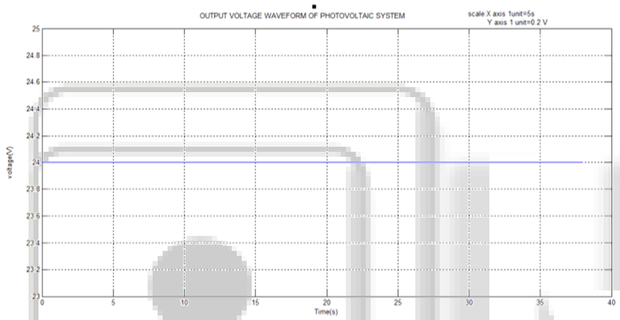

Fig. 4: Output Voltage of Photovoltaic System

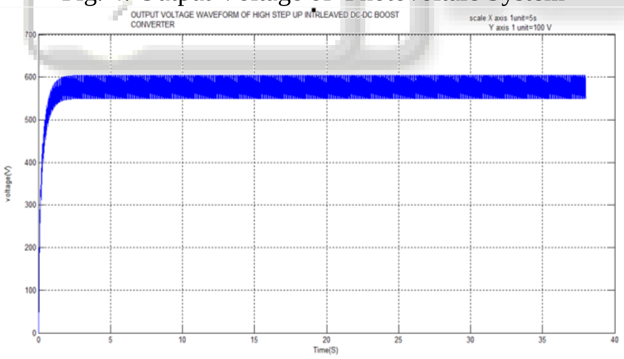

Fig. 5: Output Voltage Waveform of High Step-Up Interleaved DC-DC Boost Converter With Voltage Multiplier Module

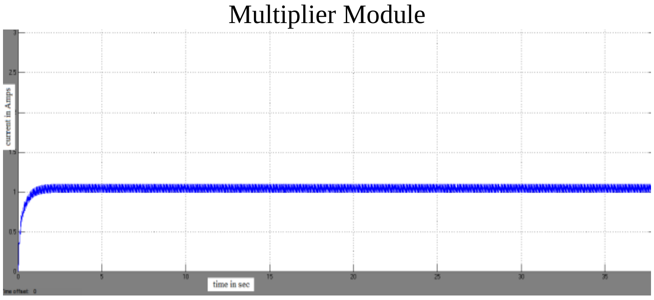

Fig. 6: Output Current Waveform of High Step-Up Interleaved DC-DC Boost Converter With Voltage Multiplier Module

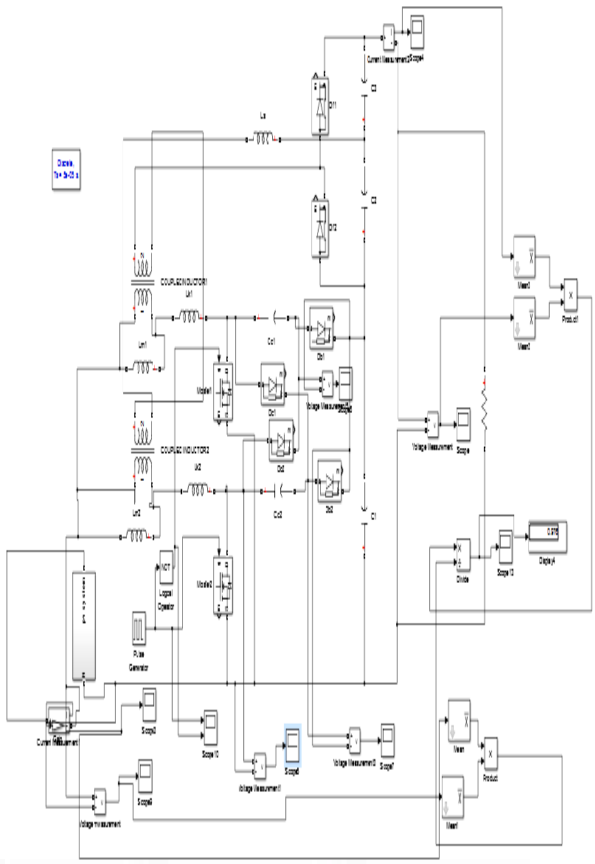

Fig. 7: Simulation Model of High Step Up Interleaved DC-DC Boost Converter With Voltage Multiplier Module For Photovoltaic System

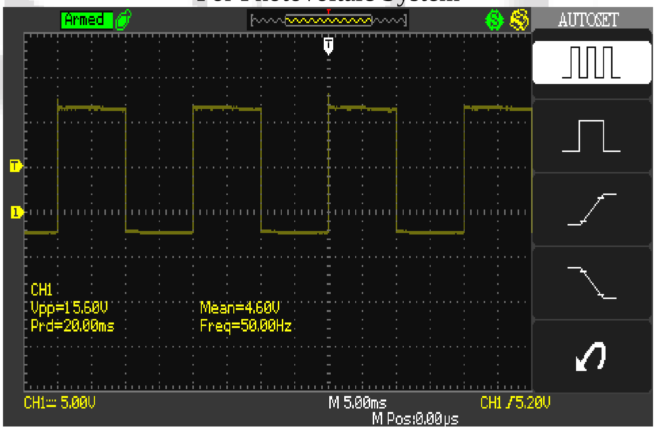

Fig. 8: Switching Signal of Switch S_1 And S_2 Of Hardware

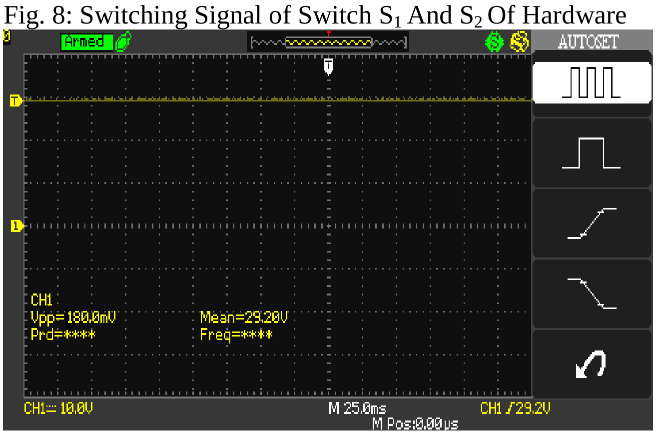

Fig. 9: Output Voltage of Hardware Setup

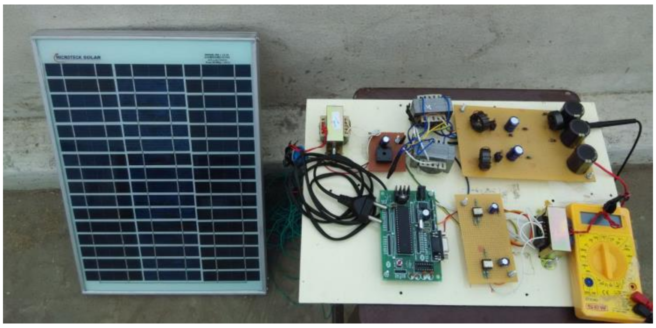

Fig 10: Hardware Setup of Interleaved DC-DC Boost Converter With Voltage Multiplier

IV. CONCLUSION

This paper has proposed the High Step Up Interleaved DC-DC Boost Converter with Voltage Multiplier Module for Photovoltaic System, which is the solution for converting extremely low voltage coming from energy harvesting power supplies like photovoltaic system to high voltage. The High Step Up Interleaved DC-DC Boost Converter with Voltage Multiplier Module for Photovoltaic System has been simulated. The converter employed two coupled inductors and voltage multiplier module in conjunction with conventional interleaved DC-DC boost converter. The proposed converter has been successfully implemented in an efficiently high step-up conversion through the voltage multiplier module.

The performance of the proposed converter is confirmed from the output waveforms obtained from the simulation, which is done for boosting 24V to 600V and hardware setup is done with 12V input voltage. Furthermore, the efficiency is 97.5%which is showed in simulation. Thus the proposed converter is suitable for renewable energy applications that need high step-up conversion.

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