HIGH INTENSIFY INTERLEAVED CASCADED CONVERTER WITH RENEWABLE ENERGY SYSTEM

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ABSTRACT

A novel high intensify converter, which is suitable for renewable energy system, is proposed in this project. Through a voltage multiplier module composed of switched capacitors and coupled inductors. The configuration of the proposed converter not only reduces the current stress but also constrains the input current ripple, which decreases the conduction losses and lengthens the lifetime of the input source. In addition, due to the lossless passive clamp performance, leakage energy is recycled to the output terminal. Hence, large voltage spikes across the main switches are alleviated, and the efficiency is improved.

Keywords: Boost–Flyback Converter, High Step-Up, Photovoltaic (PV) System, Voltage Multiplier Module.

I. INTRODUCTION

The typical renewable energy system consists of renewable energy sources, a step-up converter, and an inverter for ac application. A conventional interleaved boost converter obtains high step-up gain without operating at extreme duty ratio. High step-up single-switch converters are unsuitable to operate at heavy load given a large input current ripple, which increases conduction losses. Conventional step-up converters, such as the boost converter and fly back converter, cannot achieve a high step-up conversion with high efficiency because of the resistance of elements or leakage inductance.Photovoltaic (PV) systems have been used for many decades. Today, with the focus on greener sources of power, PV has become an important source of power for a wide range of applications. Improvements in converting light energy into electrical energy as well as the cost reductions have helped create this growth. Even with higher efficiency and lower cost, the goal remains to maximize the power from the PV system under various lighting conditions. Unfortunately, PV generation systems have two major problems: the conversion efficiency of electric power generation is very low especially under low irradiation conditions, and the amount of electric power generated by solar arrays changes continuously with weather conditions.

To integrate switched capacitors into an interleaved boost converter may make voltage gain reduplicate, but no employment of coupled inductors causes the step-up voltage gain to be limited. Oppositely, 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. Thus, the synchronous employment of coupled inductors and switched capacitors is a better concept moreover high step-up gain, high efficiency, and low voltage stress is achieved even for high-power applications.

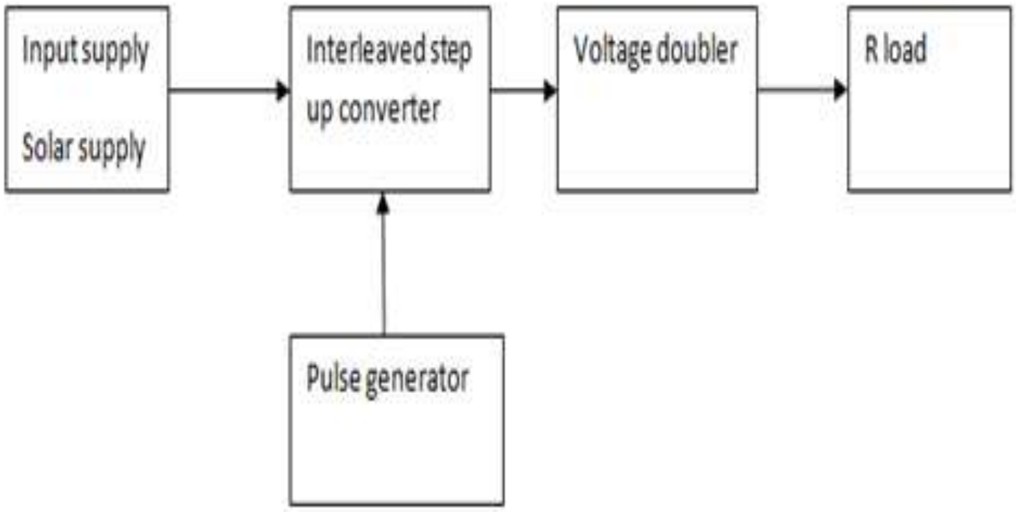


Fig.1 Block Diagram

A boost converter (step-up converter) is a DC-to-DC power converter with an output voltage greater than its input voltage. It is a class of switched-mode power supply (SMPS) containing at least two semiconductors such as a diode and a transistor and at least one energy storage element, a capacitor, inductor, or the two in combination. Filters made of capacitors or sometimes in combination with inductors are normally added to the output of the converter to reduce output voltage ripple. Power for the boost converter can come from any suitable DC sources, such as batteries, solar panels, rectifiers and DC generators. A process that changes one DC voltage to a different DC voltage is called DC to DC conversion. A boost converter is a DC to DC converter with an output voltage greater than the source voltage. A boost converter is sometimes called a step-up converter since it "steps up" the source voltage. Since power (P=VI) must be conserved, the output current is lower than the source current.In a boost converter, the output voltage is always higher than the input voltage.

A pulse generator is either an electronic circuit or a piece of electronic test equipment used to generate rectangular pulses. Simple bench pulse generators usually allow control of the pulse repetition rate (frequency), pulse width, delay with respect to an internal or external trigger and the high- and low-voltage levels of the pulses. More-sophisticated pulse generators may allow control over the rise time and fall time of the pulses. Pulse generators are available for generating output pulses having widths (duration) ranging from minutes down to under 1 pico second. Pulse generators are generally voltage sources, with true current pulse generators being available only from a few suppliers. Pulse generators may use digital techniques, analogue techniques, or a combination of both techniques to form the output pulses.

A voltage doublder is an electronic circuit which charges capacitors from the input voltage and switches these charges in such a way that, in the ideal case, exactly twice the voltage is produced at the output as at its input. The simplest of these circuits are a form of rectifier which take an AC voltage as input and output a doubled DC voltage. The switching elements are simple diodes and they are driven to switch state merely by the alternating voltage of the input. DC to DC voltage doublers cannot switch in this way and require a driving circuit to control the switching. They frequently also require a switching element that can be controlled directly, such as a transistor, rather than relying on the voltage across the switch as in the simple AC to DC case. Voltage doublers are a variety of voltage multiplier circuit. Many (but not all) voltage doubler circuits can be viewed as a single stage of a higher order multiplier: cascading identical stages together achieves a greater voltage multiplication.

II. HIGH STEP-UP INTERLEAVED CONVERTER WITH A VOLTAGE MULTIPLIER MODULE

The proposed high step-up interleaved converter with a voltage multiplier module. The voltage multiplier module is composed of two coupled inductors and two switched capacitors and is inserted between conventional interleaved boost converters to form a modified boost fly back forward interleaved structure.

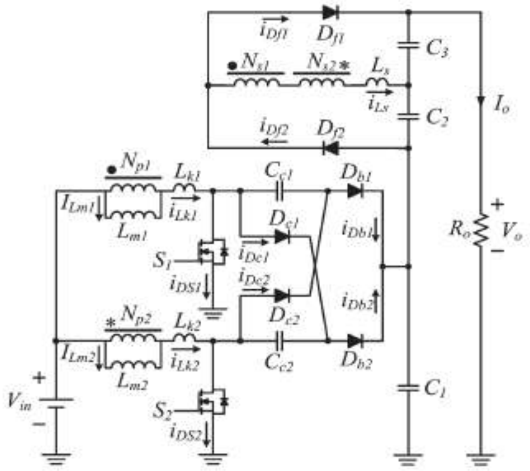
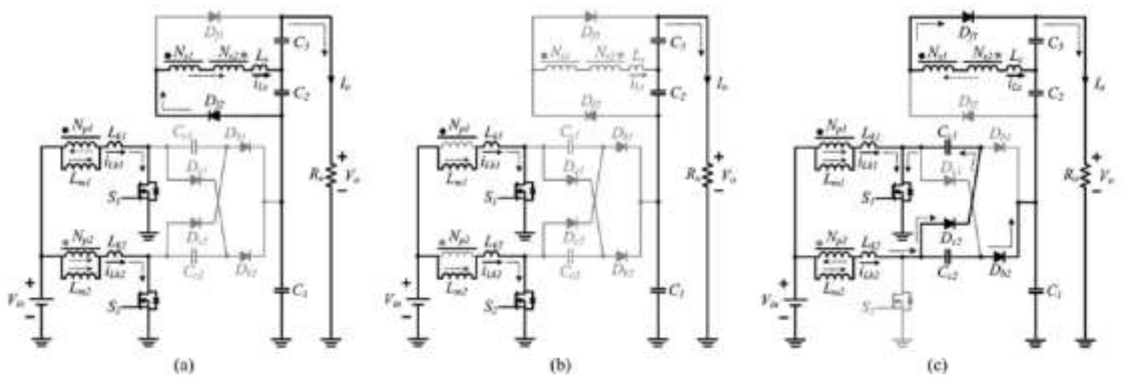


Fig.2 Circuit Diagram of the Proposed Converter

2.1 Operating Principle

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 $N_p$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 turn ratios of the coupled inductors are the same. The coupling references of the inductors are denoted by " ·" and " * ".

The circuit of the proposed converter is shown in Fig.4.1. Where L_{m1} and L_{m2} are the magnetizing inductors; L_{k1} and L_{k2}represent the leakage inductors; L_s represents the series leakage inductors in the secondary side; S_1 and S_2 denote the power switches; C_{c1} and C_{c2} are the switched capacitors; and C_1, C_2, and C_3 are the output capacitors. D_{c1} and D_{c2} are the clamp diodes, D_{b1} and D_{b2} represent the output diodes for boost operation with switched capacitors, D_{f1} and D_{f2} represent the output diodes for fly back forward operation, and n is defined as turn ratio N_s/N_p. In the circuit analysis, the proposed converter operates in continuous conduction mode (CCM), and the duty cycles of the power switches during steady operation are greater than 0.5 and are interleaved with a 180◦ phase shift. The key steady waveform in one switching period of the proposed converter contains eight modes



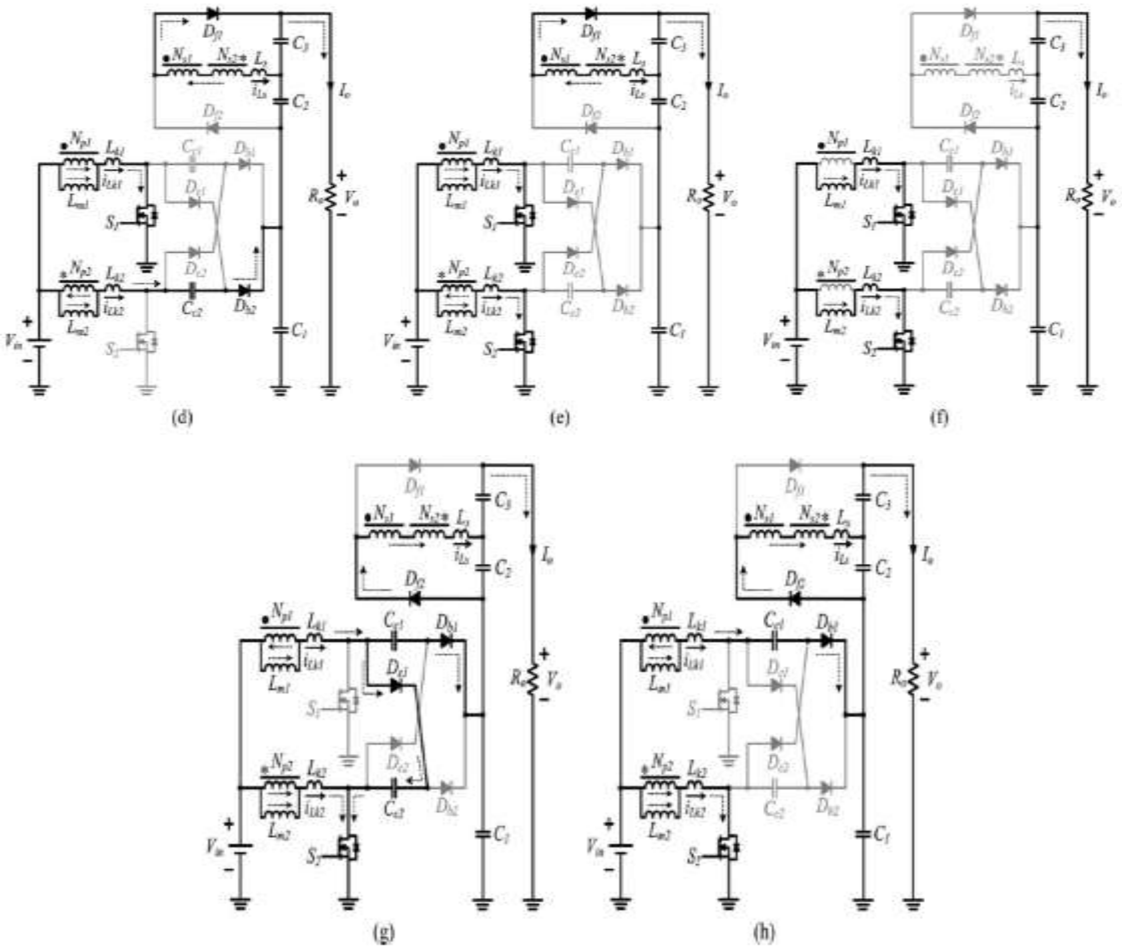


Fig.3 Operating modes of the proposed converter. (a) Mode I [*to*, *t*1]. (b) Mode II [*t*1, *t*2]. (c) Mode III [*t*2, *t*3]. (d) Mode IV [*t*3, *t*4]. (e) Mode V [*t*4, *t*5].(f) Mode VI [*t*5, *t*6]. (g) Mode VII [*t*6, *t*7]. (h) Mode VIII [*t*7, *t*8].

MODE 1: In mode 1 operation [t_0, t_1], at t = t_0, the power switch S_2 remains in ON state, and the other power switch S_1 begins to turn on. The diodes D_{c1}, D_{c2}, D_b1, D_{b2}, and D_{f1} are reversed biased, as shown in Fig. The series leakage inductors Ls quickly release the stored energy to the output terminal via fly back forward diode D_{f2}, and the current through series leakage inductors L_s decreases to zero. Thus, the magnetizing inductor Lm1 still transfers energy to the secondary side of coupled inductors. The current through leakage inductor L_{k1} increaseslinearly and the other current through leakage inductor L_{k2} decreases linearly.

MODE 2: In this mode [t_1, t_2]: At t = t_1, both of the power switches S_1 and S_2 remain in ON state, and all diodes are reversed biased. Both currents through leakage inductors L_{k1} and L_{k2} are increased linearly due to charging by input voltage source V_{in}

MODE 3: In this mode [t_2, t_3] at t = t_2, the power switch S1 remains in ON state, and the other power switch S_2 begins to turn off. The diodes D_c1, D_b1, and D_f2 are reversed biased. The energy stored in magnetizing inductor L_{m2}

transfers to the secondary side of coupled inductors, and the current through series leakage inductors Ls flows to output capacitor C_3 via fly back forward diode D_{f1}

MODE 4: In this mode [t_3, t_4]at t = t_3, the current i_{Dc2} has naturally decreased to zero due to the 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 states except the clamp diode D_{c2}.

MODE 5: In this Mode [t_4, t_5] at t = t_4, the power switch S_1 remains in ON state, and the other power switch S2 begins to turn on. The diodes D_{c1}, D_{c2}, D_{b1}, D_{b2}, and Df2 are reversed biased. The series leakage inductors Ls quickly release the stored energy to the output terminal via fly back forward diode D_{f1}, and the current through series leakage inductors decreases to zero. Thus, the magnetizing inductor L_{m2} still transfers energy to the secondary side of coupled inductors. The current through leakage inductor L_{k2} increases linearly and the other current through leakage inductor L_{k1} decreases linearly

MODE 6: In this Mode [t_5, t_6] at t = t_5, both of the power switches $S_1$and S_2 remain in ON state, and all diodes are reversed biased, as shown in Fig. 3(f). Both currents through leakage inductors L_{k1} and L_{k2} are increased linearly due to charging by input voltage source V_{in}.

MODE 7: In this mode [t_6, t_7] at, t = t_6, the power switch S_2 remains in ON state, and the other power switch S_1 begins to turn off. The diodes D_{c2}, D_{b2}, and D_{f1} are reversed biased. The energy stored in magnetizing inductor Lm1 transfers to the secondary side of coupled inductors, and the current through series leakage inductors flows to output capacitor C_2 via fly back forward diode D_{f2}. The voltage stress on power switch S1 is clamped by clamp capacitor Cc2 which equals the output voltage of the boost converter. The input voltage source, magnetizing inductor L_{m1}, leakage inductor L_{k1}, and clamp capacitor C_{c1} release energy to the output terminal; thus, V_{C1} obtains double output voltage of the boost converter

MODE 8: In this mode [t_6, t_7] at, t = t_6, the power switch S_2 remains in ON state, and the other power switch S1 begins to turn off. The diodes D_{c2}, D_{b2}, and D_{f1} are reversed biased. The energy stored in magnetizing inductor L_{m1} transfers to the secondary side of coupled inductors, and the current through series leakage inductors flows to output capacitor C_2 via fly back forward diode D_{f2}.

2.2 Steady-State Analysis

The transient characteristics of circuitry are disregarded to simplify the circuit performance analysis of the proposed converter in CCM, and some formulated assumptions are as follows.

- All of the components in the proposed converter are ideal.
- Leakage inductors L_{k1}, L_{k2}, and $L_s$are neglected.
- Voltages on all capacitors are considered to be constant because of infinitely large capacitance.
- Due to the completely symmetrical interleaved structure, the related components are defined as the corresponding symbols such as D_{c1} and D_{c2} defined as D_c.

2.2.1 Step-Up Gain

The voltage on clamp capacitor $C_c$can be regarded as an output voltage of the boost converter. Thus, voltage V_{Cc}can be derived from,

$$V_{Cc}=\frac{1}{1-D}V_{in} \quad (1)$$

When one of the switches turns off, voltage V_{C1} can obtain a double output voltage of the boost converter derived from,

$$V_{c1}=\frac{1}{1-D}V_{in}+V_{Cc}=\frac{2}{1-D}V_{in} \quad (2)$$

The output filter capacitors C_2 and C_3 are charged by energy transformation from the primary side. When S_2 is in ON state and S_1 is in OFF state, V_{C2} is equal to the induced voltage of N_{s1} plus the induced voltage of N_{s2}, and when S_1 is in ON state and S_2 is in OFF state, V_{C3} is also equal to the induced voltage of N_{s1} plus the induced voltage of N_{s2}. Thus, voltages V_{C2} and V_{C3} can be derived from,

$$V_{c2} = V_{c3} = n.V_{in}(1+\frac{D}{1-D}) = \frac{n}{1-D} V_{in} \quad (3)$$

The output voltage can be derived from,

$$V_o=V_{c1}+V_{c2}+V_{c3} =\frac{2n+2}{1-D}V_{in} \quad (4)$$

In addition, the voltage gain of the proposed converter is,

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

Equation (5) confirms that the 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 turn ratio n of one; the voltage gain reaches 30 at a turn ratio n of five.

2.2.2 Voltage Stress on Semiconductor Component

The voltage ripples on the capacitors are ignored to simplify the voltage stress analysis of the components of the proposed converter. The voltage stress on power switch S is clamped and derived from,

$$Vs1 = Vs2 =\frac{2}{1-D}Vin = \frac{1}{2n+2} Vo \quad (6)$$

Equation (6) confirms that low-voltage-rated MOSFET with low RDS (ON) can be adopted for the proposed converter to reduce conduction losses and costs. The voltage stress on the power switch S accounts for a fourth of output voltage V_o, even if turn ratio n is one. This feature makes the proposed converter suitable for high step-up and high-power application. The voltage stress on diode Dc is equal to V_{C1}, and the voltage stress on diode $D_b$is voltage V_{C1} minus voltage V_{Cc}. These voltage stresses can be derived from,

$$V_{Dc1} = V_{Dc2} =\frac{2}{1-D}V_{in} = \frac{1}{n+1} V_o \quad (7)$$

$$V_{Db1} = V_{Db2} = V_{c1}-V_{c2} = \frac{1}{1-D}V_{in} = \frac{1}{2n+2} V_o \quad (8)$$

The voltage stress on diode D_b is close to the voltage stress on power switch S. Although the voltage stress on diode $D_c$is larger, it accounts for only half of output voltage $V_o$at a turn ratio n of one. The voltage stresses on the diodes are lower as the voltage gain is extended by increasing turn ratio n. The voltage stress on diode D_f equals the V_{C2} plus V_{C3}, which can be derived from,

$$V_{Df1} = V_{Df2} =\frac{2n}{1-D}V_{in} = \frac{n}{n+1} V_o \quad (9)$$

Although the voltage stress on the diode D_f increases as the turn ratio n increases, the voltage stress on the diodes D_f is always lower than the output voltage. The relationship between the voltage stresses on all the semiconductor components and the turn ratio n.

III. SIMULATION OF HIGH INTENSIFY INTERLEAVED CASCADED CONVERTER WITH RENEWABLE ENERGY SYSTEM

MATLAB is a software package for computation in engineering, science, and applied mathematics.It offers a powerful programming language, excellent graphics, and a wide range of expertknowledge.MATLAB is much easier to use and comes with a huge standard library. Simulink (Simulation and Link) is an extension of MATLAB by Math works Inc. It works with MATLAB to offer modeling, simulating, and analyzing of dynamical systems under a graphical user interface (GUI) environment.

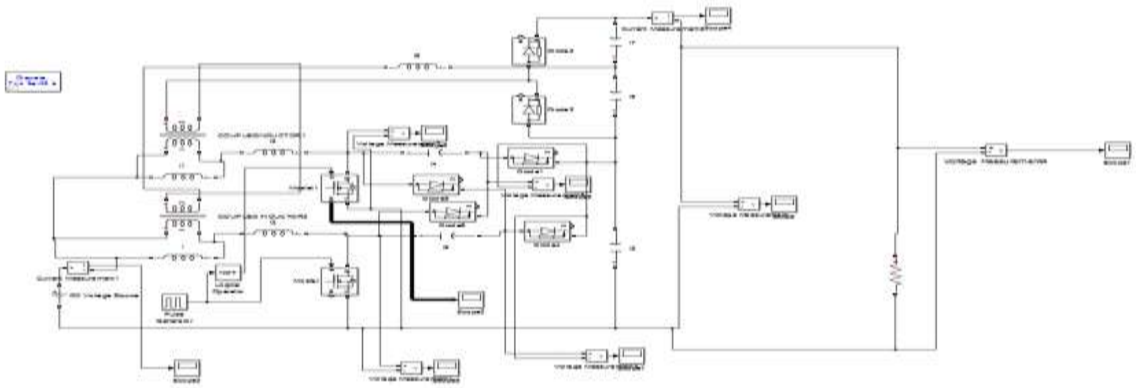


Fig.4 Matlab Simulation of Interleaved Cascaded Converter

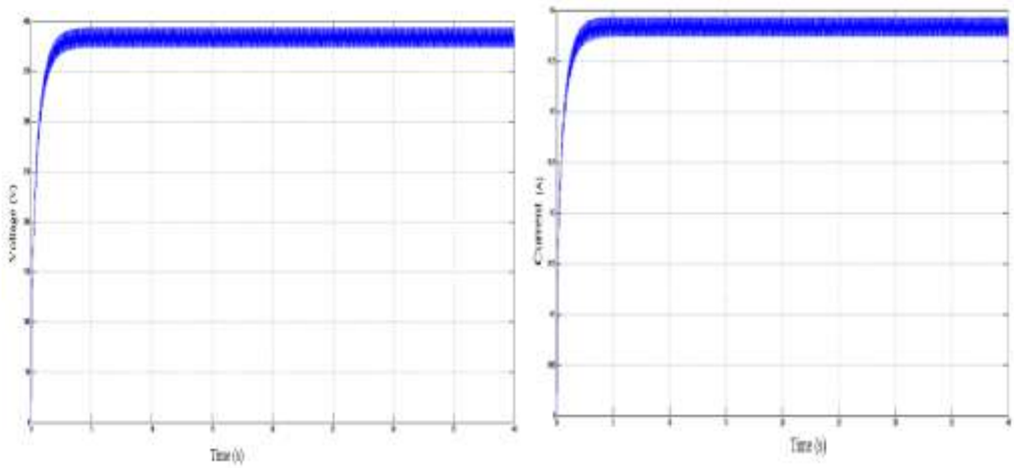


Fig.5 Output Voltage and Current Waveform of Converter

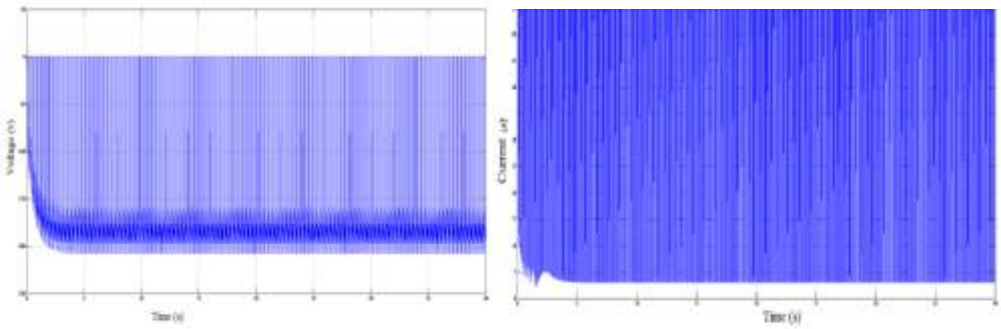


Fig.6 Reverse conduction voltage and Current output

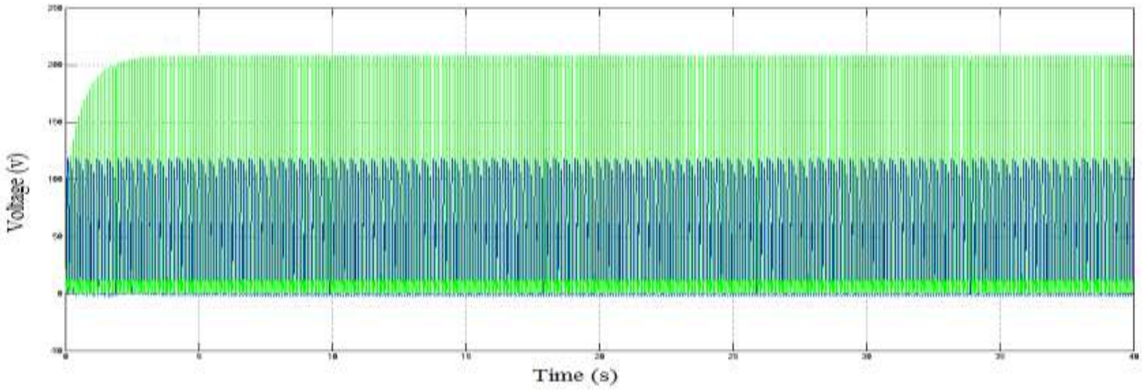


Fig.7 MOSFET Output voltage

IV. CONCLUSION

This paper has presented the theoretical analysis of steady state, related consideration, and simulation results for the proposed converter. The proposed converter has successfully implemented an efficient high step-up conversion through the voltage multiplier module. The interleaved structure reduces the input current ripple and distributes the current through each component. In addition, the lossless passive clamp function recycles the leakage energy and constrains a large voltage spike across the power switch. Meanwhile, the voltage stress on the power switch is restricted and much lower than the output voltage (380 V). Furthermore, the full-load efficiency is 96.4% at P_o= 1000 W, and the highest efficiency is 97.1% at Po = 400 W. Thus, the proposed converter is suitable for high-power or renewable energy applications that need high step-up conversion.

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