IJIREEICE

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering
ISO 3297:2007 Certified
Vol. 4, Issue 9, September 2016

# A Non Isolated Single-Switch High Step-Up Converter with Low Voltage Stress

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**Abstract:** A non-isolated single switch high step-up converter with low voltage stress is presented in this paper. The converter is derived based on the conventional fly back converter. A clamping diode as well as a voltage doubler circuit is used in order to reduce the voltage stress across the switch and diodes. Another converter can also be derived by rearranging the components and adding a capacitor to the circuit. Since the converter has low voltage stress, lower voltage rated switch and diodes are used, which result in high efficiency with low conduction losses. The MATLAB simulation of the converter is done using 24V input voltage and 250V/125W output. The lower stress on the switch and diodes are verified by the simulation results.

**Keywords:** High step-up converter, low voltage stress, non-isolated, reverses recovery, single switch, voltage doubler.

## I. INTRODUCTION

The proposed converter can be used in renewable application as well as dc back energy systems like solar arrays, fuel cells, UPS and high intensity discharge(HID) lamps for auto mobiles. Usually conventional step-up converters have features of large input current and high output voltage. Severe reverse recovery problem in diodes due to high output voltage, hence current stress and voltage stress increases.

The conventional boost converter can achieve a high voltage gain and high efficiency only with a reasonable duty ratio. Due to the losses in the power switch and the diodes, equivalent series resistance (ESR) of inductor and capacitor and reverse recovery problem of diodes; the conversion efficiency and step-up voltage gain are limited. In converters adopting the transformer, like fly back, forward, push pull, half bridge and full bridge; the high voltage gain can be obtained by adjusting the turns ratio of transformer. The flyback converter is very widely used in low power applications.

The primary switch and secondary diode of the converter suffer from high voltage stress due to leakage inductance of the transformer. Thus, the use of flyback converter for higher power applications is limited.

A non-isolated single switch high step-up converter is derived from conventional fly back converter using clamping diode and voltage doubler structure in order to overcome the aforementioned problems. By an additional capacitor semiconductor voltage stress can be further reduced. The following section shows the derivation and analysis with operational principles, features and design considerations. The validity of the study is verified using MATLAB simulations.

## II. TOPOLOGY DERIVATION OF PROPOSED CONVERTER

The fly back converter can be used in achieving high step up gain in low power applications. The topology derivation of the proposed converter from conventional fly back is shown in Fig 1.

The flyback converter in Fig 1(i) is a simple structure with high voltage stresses on the primary switch and secondary diodes due to resonance between leakage inductance of the transformer and parasitic capacitance of the semiconductors.

A voltage doubler circuit is adopted to reduce the voltage stress on the diode as in Fig 1(ii). The voltage stress on the diode is clamped to $V_o$and on the primary switch is limited to $V_D$ by a clamping diode DP, which connects the primary and secondary ground.

The capacitor $C_D$ shown in Fig 1(iii), act as a clamping voltage source for the switch and voltage doubler capacitors. The voltage across $C_D$ is the voltage doubler value = $(1-D)V_o$. In order to reduce the voltage stress further, an auxiliary voltage source $V_{aux}$ is connected to diode $D_{o1}$ (as in fig 1(iv)) and it becomes $V_0$-$V_{aux}$. If $V_{aux}$ is used to boost output voltage the switch can have lower voltage stress, which results the gain of the boost converter.

In Fig 1(v), $D_{o1}$ and $V_{aux}$ is replaced by $N_S$ and $C_D$. Then the output voltage of the boost converter is obtained across the boost capacitor $C_B$, $V_S/(1-D)$ to which the switch is clamped. The output diodes are clamped to $V_o$-$V_B$ in the proposed converter. Thus the proposed converter is derived from the conventional fly back converter as shown in Fig 1(vi). Low voltage rated devices are used in the converter to reduce the conduction losses.

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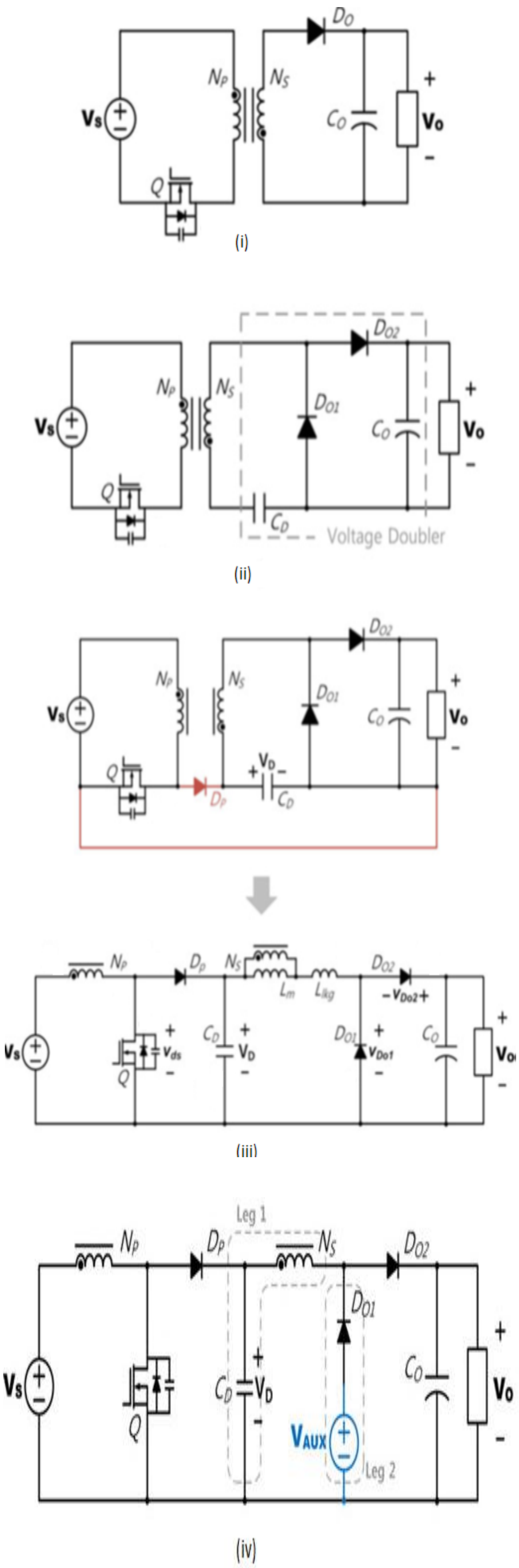


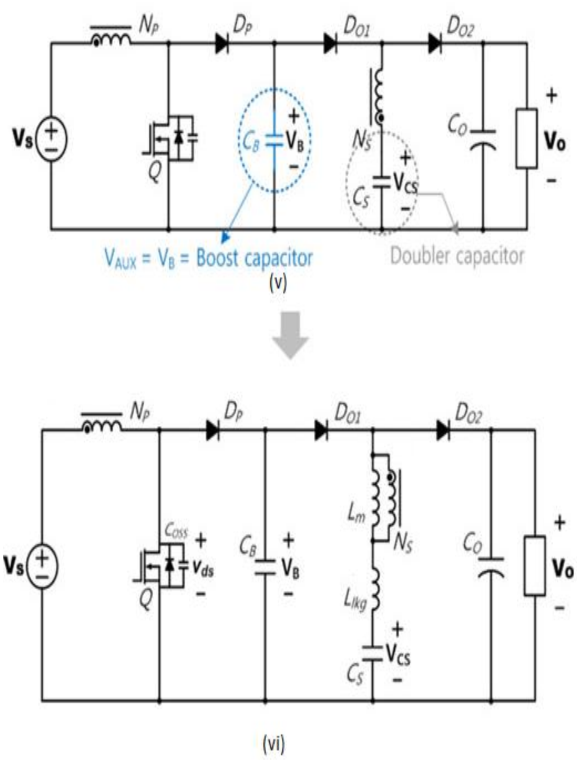


Fig 1: Derivation of proposed converter from flyback converter

## III. OPERATIONAL PRINCIPLE

The converter switching period is subdivided into five operational modes as shown in Fig 2. It is operated in a duty ratio D. Several assumptions are made in order to illustrate the steady state operation and are as follows:

1) all parasitic components except the specified one in Fig 1(vi) are neglected;

2) the parasitic capacitance $C_{OSS}$of the switch Qis small enough;

3) the output voltage VO and capacitor voltages $V_B$and $V_{CS}$are constant during a switching cycle.

Mode 1 [to-t1]: In this mode, the switch Q is turned on. The leakage current $i_{lkg}(t)$ decreases with the slope of $(V_{CS}- nV_S- V_O)/L_{lkg}$and the difference between the magnetizingcurrent $i_{Lm}(t)$ and the leakage current is reflected to the primarycurrent $i_{in}(t)$.

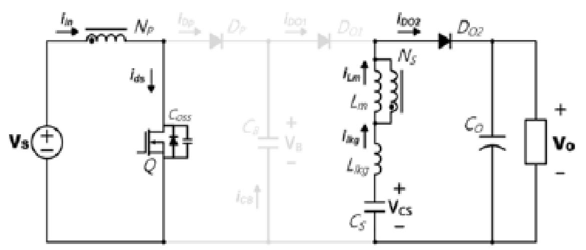

Fig. 2 (i): Mode 1 operation

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$i_{lkg}(t)$, $i_{Lm}(t)$, and $i_{in}$ (t) can be expressed asfollows:

$$i_{lkg}(t) = \frac{V_{CS} - nV_S\, t - V_O}{L_{lkg}}(t - t_0) + i_{lkg}(t_0) \qquad (3.1)$$

$$i_{Lm}(t) = \frac{nV_S}{L_m}(t - t_0) + i_{Lm}(t_0) \qquad (3.2)$$

$$i_{in}(t) = n\,(i_{Lm}(t) - i_{lkg}(t)) \qquad (3.3)$$

Where,

$$i_{lkg}(t_0) = i_{Lm}(t_0) = \left(\frac{D^2(nV_s + V_B - V_{cs})}{L_{lkg}\,(1-D)} - \frac{nDV_s}{L_m}\right)\frac{T_S}{2} \qquad (3.4)$$

Mode 2 [$t_1 - t_2$]: The mode begins when $i_{lkg}(t)$ reaches zero. The diode $D_{O1}$ is turned on and the leakage current flows through it. The diode $D_{O2}$ is turned off and its voltage stress is clamped to $V_O - V_B$. The leakage current $i_{lkg}(t)$ charges the capacitor CS and can be expressed as follows:

$$i_{lkg}(t) = \frac{V_{CS} - nV_S - V_B}{L_{lkg}}(t - t1) \qquad (3.5)$$

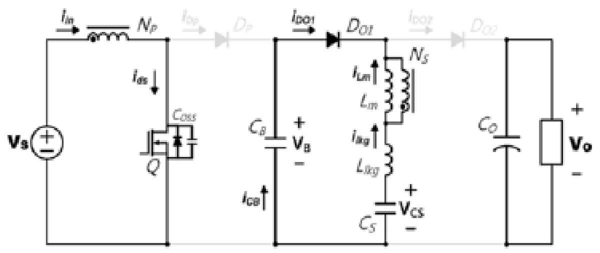


Fig. 2 (ii): Mode 2 operation

Mode 3 [$t_2 - t_3$]: This mode begins when the switch Q is turned off. The clamping diode $D_P$is turned on, and the voltage stress on the switch is clamped to $V_B$. The leakage current increases and the difference between the magnetizing current $i_{Lm}(t)$, and the leakage current is reflected to the primary side through the diode $D_P$. $i_{lkg}(t)$ and $i_{Lm}(t)$ can be expressed as follows:

$$i_{lkg}(t) = \frac{n(V_B - V_S) + V_{CS} - V_B}{L_{lkg}}(t - t2) + i_{lkg}(t_2) \qquad (3.6)$$

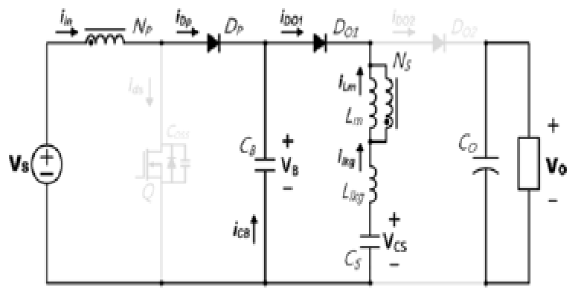


Fig. 2(iii) : Mode 3 operation

$$i_{Lm}(t) = \frac{n(V_S - V_B)}{L_m}(t - t2) + i_{Lm}(t_2) \qquad (3.7)$$

Where,

$$i_{Lm}(t_2) = \frac{n\,V_S}{L_m}DT_S + i_{lkg}(t_o) \qquad (3.8)$$

Mode 4 [$t_3 - t_4$]: This mode begins when $i_{lkg}(t)$ reaches zero. The diode $D_{O2}$ is turned on and the leakage current flows through it. The diode DO1 is turned off, and its voltage stress is clamped to $V_O - V_B$. The leakage current $i_{lkg}(t)$ discharges the capacitor $C_S$ and increases more slowly unlike the converter in Fig. 1(c). This is because the voltage stress on the capacitor CB is lower than that on the capacitor $C_D$in Fig. 1(c). $i_{lkg}(t)$ can be expressed as follows:

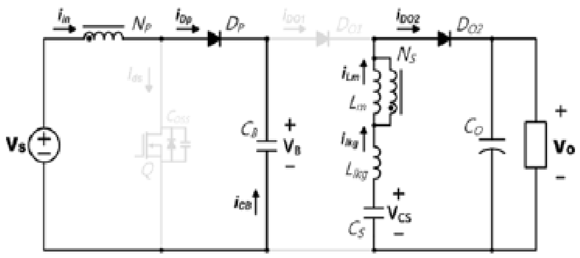


Fig. 2(iv) : Mode 4 operation

$$i_{lkg}(t) = \frac{n(V_C - V_S) + V_{CS} - V_O}{L_{lkg}}(t - t3) \qquad (3.9)$$

Mode 5 [$t_4 - t_5$]: This mode begins when $i_{lkg}(t)$ reaches the magnetizing current $i_{Lm}(t)$, which flows through the diode $D_{O2}$ . Thus, there is no current flowing in the primary side. This mode ends when the switch is turned on.

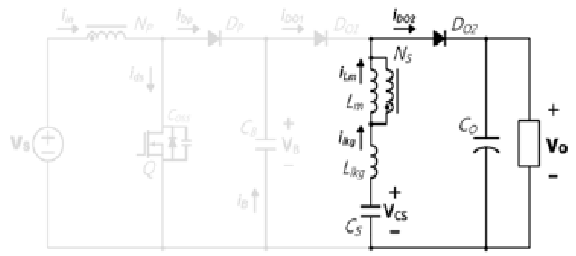


Fig. 2(v) : Mode 5 operation

## IV. SIMULATION ANALYSIS AND RESULT

The simulation analysis of a non-isolated single switch high step up converter is carried out on the basis of the following assumptions:

1) Input voltage ($V_{in}$) = 24V
2) Output voltage ($V_o$)= 250V
3) Output power($P_o$) = 125W
4) Switching frequency($f_s$) = 80KHz

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5) Duty ratio(D) = 40%
6) Leakage inductance($L_{lkg}$) = 28.15μH
7) Magnetic inductance($L_m$) = 1.31mH
8) Transformer turns($N_p$:$N_s$) = 8:45
9) Output capacitor($C_o$)=82μF

From the above assumptions, output current($I_o$), time period($T_s$), load resistance($R_o$) and capacitors $C_S$ and $C_B$ are calculated as follows:

$$\text{Time period, Ts } = \frac{1}{f_s} = \frac{1}{80 \times 1000} = 1.25e^{-5}\text{sec} \quad (4.1)$$

$$\text{Output current, } I_o = \frac{P_o}{V_o} = \frac{125}{250} = 0.5\text{A} \quad (4.2)$$

$$\text{Load resistor,} R_L = \frac{V_o}{I_o} = \frac{250}{0.5} = 500\Omega \quad (4.3)$$

$$\text{Capacitor design, } C_S = C_B = \frac{I_o}{f_s \times \Delta V_c} \quad (4.4)$$

$= \frac{0.5}{4 \times 80 \times 10^3}$ = 1.5625e-6 ≈ 2.2μF Assuming, $\Delta V_c$ = 10% $V_s$ = 4V

Where, $V_S = \frac{V_{in}}{1-D}$

The simulation is done by using MATLAB2013. The focus was on the output voltage and voltage across the switch and diodes. The closed loop Simulink model of the proposed converter using a PID controller is shown in fig 4.

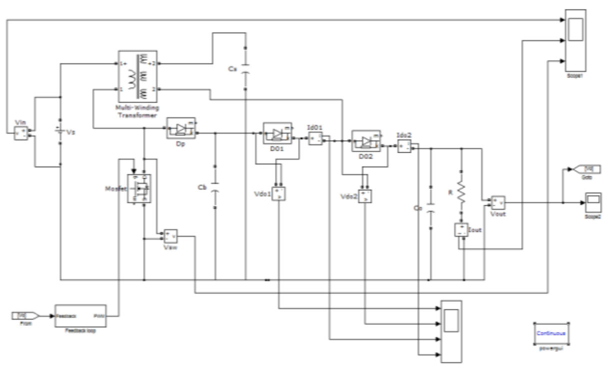

Fig 4: Closed loop simulation diagram of the proposed converter

The simulation results are shown below.

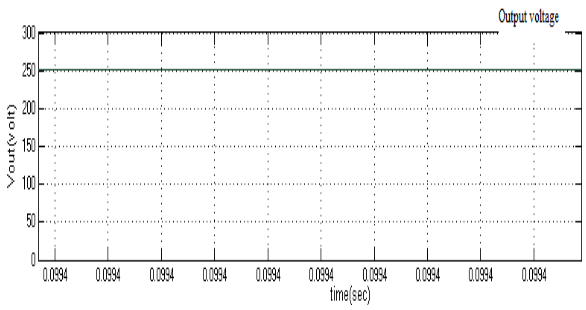


Fig 5(a): Output voltage of 250V DC

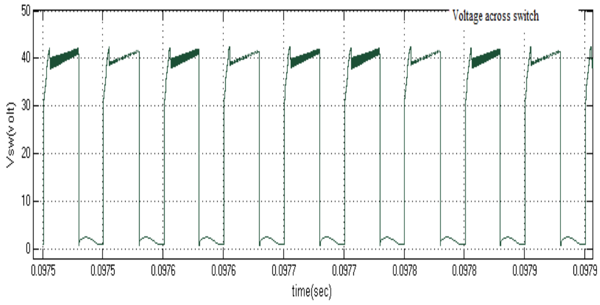


Fig 5(b): Voltage across the switch

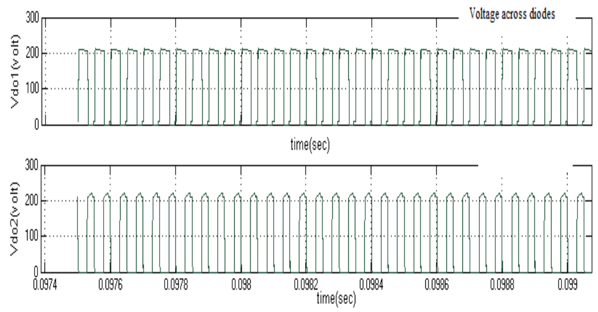


Fig 5(c): Voltage across the diodes Do1 and Do2

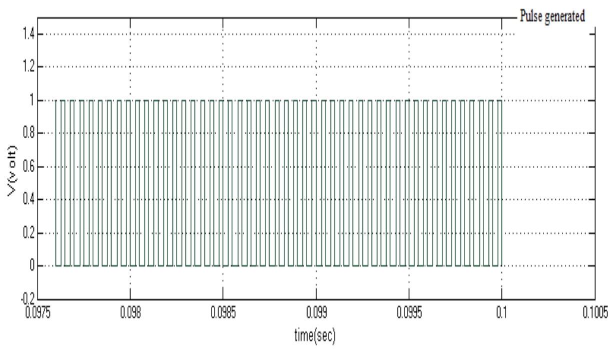


Fig 5(d): Pulse generated

## V. CONCLUSION

The experimental analysis of a non-isolated single switch high step-up converter is presented in this paper. The validity of the basic operational principle is verified by the MATLAB simulation using 12V DC input and 120V/60W output. The proposed converter has a low voltage stress across its switch and diodes. Hence the converter has lower conduction losses and reduced reverse recovery problem which lead to attain higher efficiency. Thus the converter has a high output voltage with lower voltage stress and duty ratio on comparing with the conventional circuits.

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