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Efficient Power Conversion in Common Active Clamp for Interleaved Dc-Dc Boost

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Abstracts

This project presents a high-efficiency and high-step-up non isolated interleaved dc to dc converter with a common active-clamp circuit. In the presented converter, the coupled-inductor boost converters are interleaved. A boost converter is used to clamp the voltage stresses of all the switches in the interleaved converters, caused by the leakage inductances present in the practical coupled inductors, to a low voltage level.

The leakage energies of the inter-leaved converters are collected in a clamp capacitor and recycled to the output by the clamp boost converter. The proposed converter achieves high efficiency because of the recycling of the leakage energies, reduction of the switch voltage stress, mitigation of the output diode is reverse recovery problem, and interleaving of the converters.

In many applications, high-efficiency, high-voltage step-up dc–dc converters are required as an interface between the available low voltage sources and the output loads, which are operated at much higher voltages. Examples of such applications are as follows. Different distributed energy storage components such as batteries, fuel cells, and ultra capacitors are used in the power trains of hybrid electric vehicles (HEV), electric vehicles (EV), and fuel cell vehicles

(FCV). In the present power train architectures of these vehicles, the voltage levels of the energy storage elements are usually low; whereas the motors of the vehicles are driven at much higher voltages.

The telecom and the computer industry utilize the standard batteries, with low voltage levels, as a back-up power source. The dc–dc converter, used in this case, is required to boost the low-input voltage of the batteries to the high voltage of the dc bus. Another example is the automotive headlamps, using the high-intensity discharge lamp ballasts..

Keywords: DC DC Boost.

Introduction

In a conventional boost converter, the duty ratio increases as the output to input voltage ratio increases. However, the previously mentioned applications require high-voltage step-up (step-up ratio 6 or more) and high-efficiency power conversion. Therefore, the conventional boost converters will require extreme duty ratios to meet the high-voltage step-up requirements. Under such conditions, it is a major challenge to operate the boost converters at high efficiency. This is because, with the high-output voltage, the boost switch has to block a large voltage and hence the ON-state resistance, RDS-ON, which varies almost proportionally with the square of blocking voltage, will be very high. Furthermore, the low-level input voltages cause large input currents to flow through the switches. The extreme duty-cycle operation drives short-pulsed currents with high amplitude to flow through the output diodes and the capacitors; which cause severe diode reverse recovery problem and increases in the conduction losses. The high RDS-ON of the switches, the increased conduction losses, and the severe reverse-recovery problem will degrade the efficiency and limit the power level of the conventional boost converters. Moreover, the parasitic ringing, present in the practical circuits, induces additional voltage stresses and necessitates the use of switches with higher blocking voltage ratings, which will lead to more losses.

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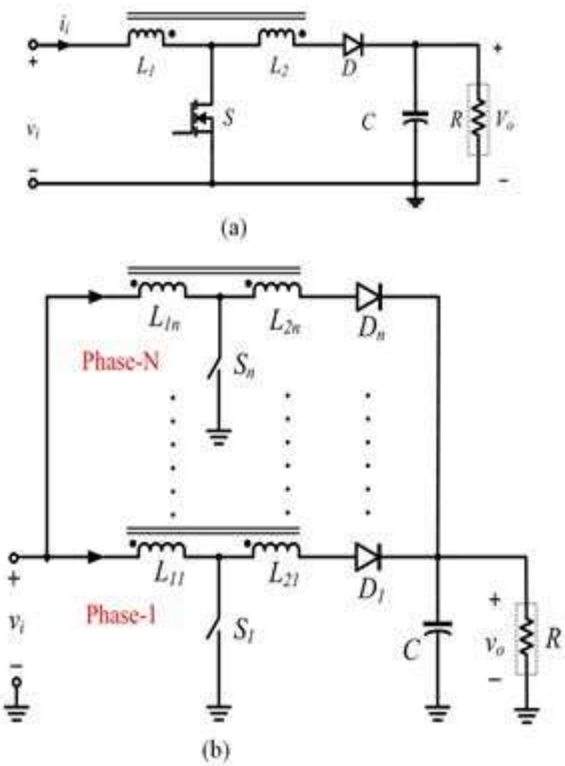

Fig. 1.1. (a) Coupled-inductor boost converter and (b) interleaved coupled inductor boost converter.

The coupled-inductor boost converter can be a good solution to the previously discussed problems of the conventional boost converter. This is because the turns ratio of the primary inductor ($L1$) to the secondary inductor ($L2$) of the coupled inductor can be effectively used to reduce the duty ratio and the voltage stress of the switch.

However, for high power applications, handling of very large input currents from the low-input voltage sources remains a practical issue. Various converter topologies using magnetically coupled inductors are reported in the literature to reduce to the extreme duty ratio operation for non isolated high step-up applications. But they are not suitable for high current and high power applications, and moreover, the circuits are complex to design and model. For high-input current, it can be proposed to interleave the coupled-inductor boost converters to process high power, and to achieve high efficiency.

Coupled-inductor boost converter and interleaving

Assume that the ideal coupled-inductor boost converter is operating under continuous conduction mode. The waveform of the primary side inductor current or the input current $iL1$ .The dynamic equation of the input current can be defined as

$$\frac{di_{L1}}{dt} = \begin{cases} \frac{v_i}{L_1}, & t \in [0, dT] \\ \frac{v_i - v_o}{L_1}\frac{1}{N+1}, & t \in [dT, T] \end{cases}$$

where vi is the input voltage, vo is the output voltage, d is the duty ratio of the converter, T is the switching time period, and N is the secondary inductor turns to primary inductor turns ratio.The steady-state operating points of the converter can be defined as: $Vi = vi$, $Vo = vo$, and $D = d$. Under steady state, the output voltage to input voltage ratio can be obtained by applying the volt-second balance condition to the primary inductor $L1$.

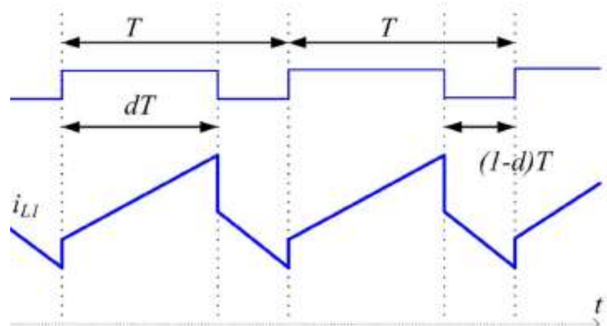

Fig 2.1 Gate pulses and primary inductor current of an ideal coupled inductor boost converter

It can be seen from that, for the same voltage gain, the duty cycle can be reduced by increasing turn ratio. Considering, the coupling between the primary and secondary inductors is ideal, the voltage stress Vcl on the switch can be obtained as

$$V_{cl} = \frac{NV_i + V_o}{N+1}$$

The switch ON-state resistance *RDS*-ON varies almost proportionally with the square of the switch voltage rating. Hence, the conduction loss in the switch of a coupled-inductor boost converter is a function of the turn ratio and the voltage step-up ratio. It would be a merit of interest to compare the switch conduction losses of a boost converter (Wsb) and a coupled inductor boost converter (Wsc). The ratio of these two losses for various turns ratio (N) and step-up ratio (Vo/Vi) are plotted in .From this figure, it can be seen that with appropriate choice of the turn numbers, the switch conduction losses in the coupled-inductor boost converter can be significantly reduced.

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Interleaved coupled-inductor converter with a common active clamp

Introduction

In the practical coupled inductors, due to the non ideal coupling between the primary and the secondary windings, there will be leakage inductances. This leakage inductance will cause high-voltage spikes when the switch is turned off. This results in a high-voltage stress across the switches and in ringing losses. It can be proposed to clamp the switch voltage to the output voltage, using a parallel diode.[see fig 5.3] In this clamp circuit, the energy stored in the leakage inductance is discharged directly to the output by the parallel diode, and the switch voltage is clamped to the output voltage.

It can be seen that this converter avoids the disadvantage of series conduction loss of the total power, but the switch voltage stress becomes equal to the output voltage. So this configuration does not take full advantages of the coupled-inductor boost topology, and hence, it is not suitable for high-step-up application where the output voltage level is high. In the proposed active clamp circuit, in each phase, a clamp-diode ($Dc1, Dc2, \ldots Dcn$) is connected to the common node of the primary inductor, the secondary inductor, and the switch of an interleaved coupled inductor boost converter. The cathode terminals of all the clamp diodes are connected to a clamp capacitor Cc.

The energies stored in the leakage inductors of the interleaved phases are discharged through the clamp diodes and gathered in the clamp capacitor Cc. Furthermore, the boost converter is used to transfer the stored energy in the clamp capacitor to the output of the interleaved converters, while maintaining the voltage level of the clamp capacitor to a lower level. The voltage stress on the switches ($S1, S2, \ldots Sn$) is decided by this clamp-capacitor voltage. It can be suggested that any other converter topology, which can perform similar boost operation while maintaining the voltage level of the clamp capacitor can be also used for the active-clamp operation.

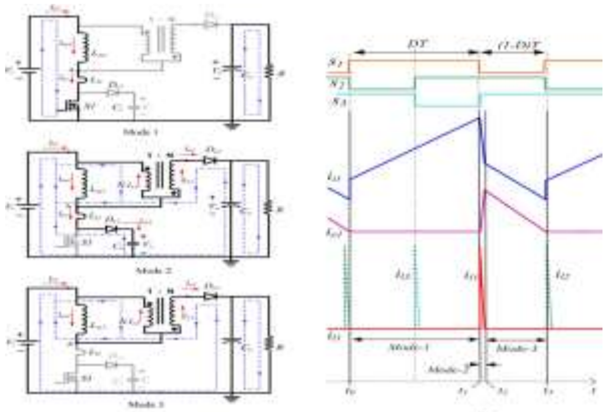

Fig. 3.1 (a) Operation modes (Mode 1: t ∈ [t0 , t1], Mode 2: t ∈ [t1 , t2], Mode 3: t [t2 -t3]) and (b) key waveforms during the operation modes.

Simulation results

Input pulse for interleaved coupled inductor boost converter

The input gate pulses applied to MOSFETS of the interleaved coupled inductor boost converters as shown in the Fig 4.1.

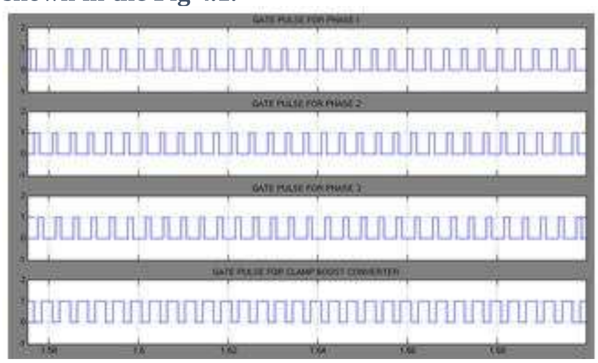

Figure 4.1 Input pulse waveform of interleaved coupled inductor boost converter

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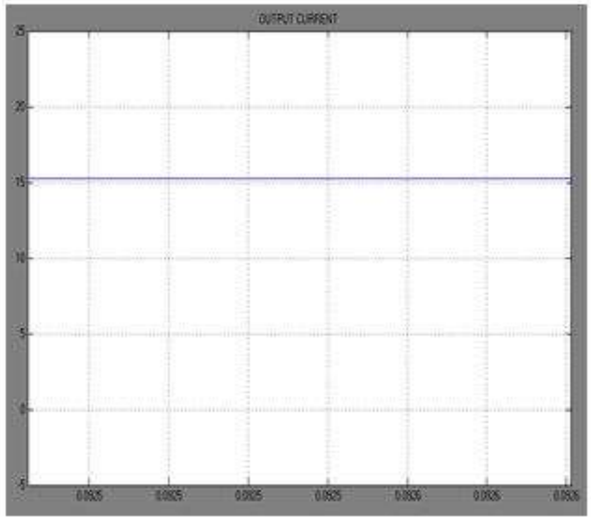

Figure 4.2 Generation of the output
Voltage

Matlab model for 11 levels cmli

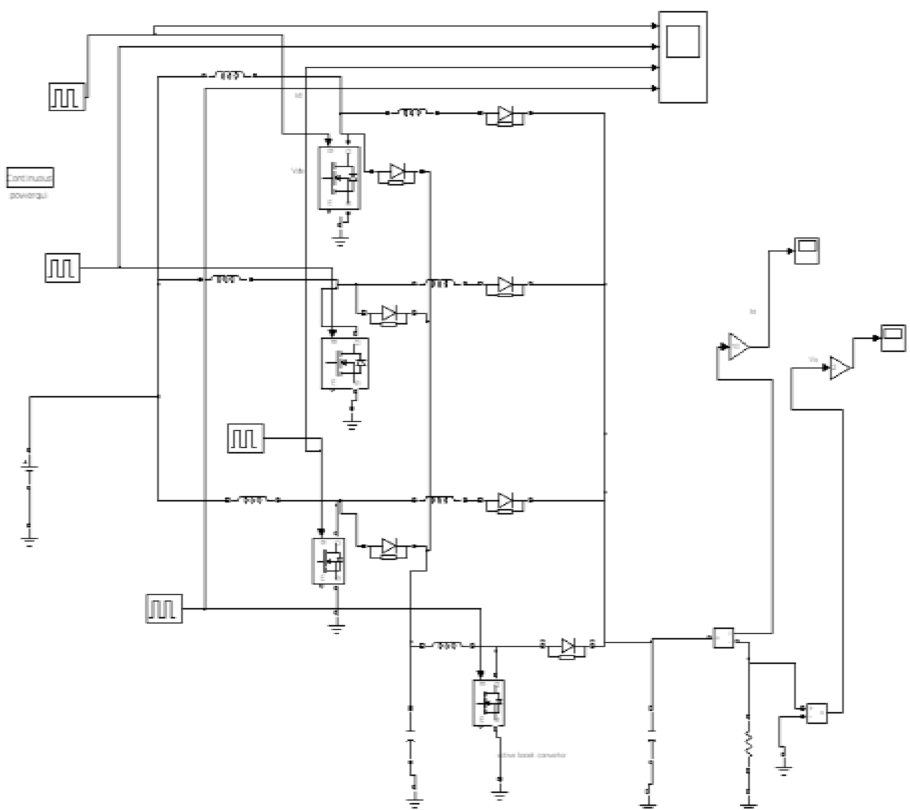

Figure 4.3 MATLAB Model Single Phase Inverter

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Conclusion

Coupled-inductor boost converters can be interleaved to achieve high-step-up power conversion without extreme duty ratio operation while efficiently handling the high-input current. In a practical coupled-inductor boost converter, the switch is subjected to high voltage stress due to the leakage inductance present in the nonideal coupled inductor. The presented active clamp circuit, based on single boost converter, can successfully reduce the voltage stress of the switches close to the low-level voltage stress offered by an ideal coupled-inductor boost converter. The common clamp capacitor of this active-clamp circuit collects the leakage energies from all the coupled-inductor boost converters, and the boost converter recycles the leakage energies to the output. Detailed analysis of the operation and the performance of the proposed converter were presented in this project. It has been found that with the switches of lower voltage rating, the recovered leakage energy, and the other benefits of an ideal coupled-inductor boost converter and interleaving, the converter can achieve high efficiency for high step-up power conversion.

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