

# An Efficient High-Step-Up Interleaved DC-DC Converter with a Common Active Clamp

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**Abstract—** The 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). Telecom and the computer industry utilize the standard batteries, with low voltage levels, as back-up power source. The automotive headlamps, using the high-intensity discharge lamp ballasts.

**Index Terms—** Electric Vehicles (EV), Fuel Cell Vehicles (FCV), Hybrid Electric Vehicles (HEV).

## I. INTRODUCTION

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. Next, the telecom and the computer industry utilize the standard batteries, with low voltage levels, as a back-up power source. In such applications, a front-end converter with dual inputs is used. 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. The dc-dc converter, used in this application, is

required to boost the low voltage level of car battery to much higher voltage level during the start-up and normal operations. Finally, few emerging applications, such as photovoltaic cells, also require high-gain dc voltage conversion. It can be noted that in all these applications, the high-step-up dc-dc converters can be no isolated but they should operate at high efficiency while taking high currents from low-voltage dc sources at their inputs.

## II. DC-DC CONVERTER

Depending on the application nature, several types of static power converters are necessary for the adequate conversion and conditioning of the energy provided by primary sources such as photovoltaic arrays, wind turbines, and fuel cells. Besides, considering that the overall cost of renewable energy systems is high, the use of high-efficiency power electronic converters is a must.

### A. Interleaved Coupled-Inductor Converter With A Common Active Clamp

The practical coupled inductors, due to the no ideal coupling between the primary and the secondary windings, there will be leakage inductances. The equivalent circuit diagram of a practical converter with the leakage inductance is shown in Fig. 1.[1] This leakage inductance will cause high-voltage spikes when the switch is turned off[2]. This causes a high-voltage stress across the switches and in ringing losses. It can be used to clamp the switch voltage to the output voltage, using a parallel diode as shown in fig 2.[3]-[5] To lower the voltage stress on the switches close to the level of the voltage stress present in an ideal coupled-inductor boost converter, a common active-clamp circuit based on a boost converter can be proposed, as shown in Fig. 3

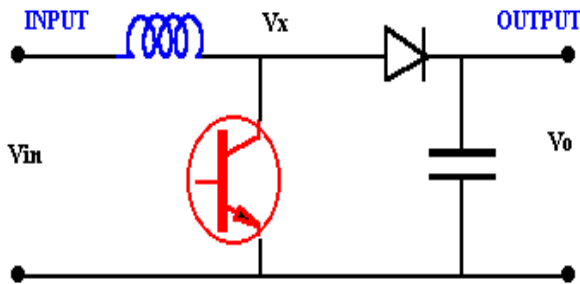


Fig. 1 Boost Converter Circuit

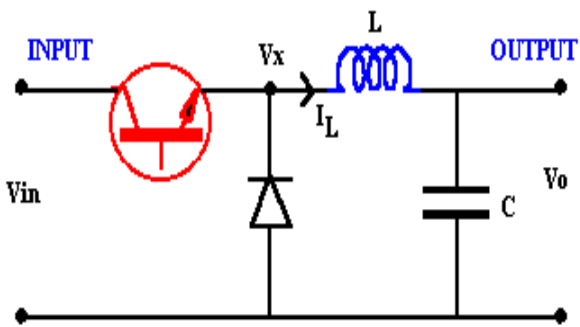


Fig. 2 Buck Converter

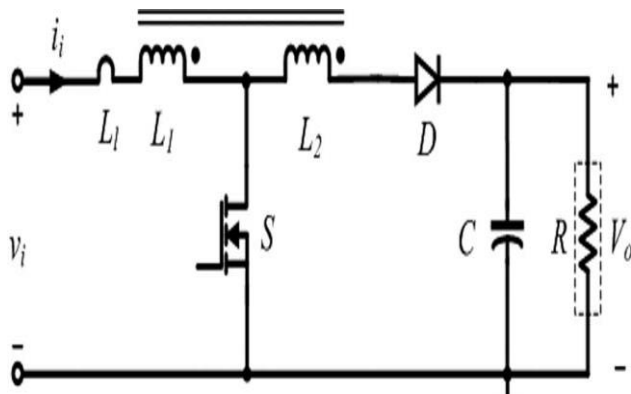


Fig. 3 Coupled-Inductor Boost Converter

In the proposed active clamp circuit, in each phase, a clamp-diode ( $D_{c1}, D_{c2}, \dots D_{cn}$ ) 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  $C_c$  [6]-[7]. The energies stored in the leakage inductors of the interleaved phases are discharged through the clamp diodes and gathered in the clamp capacitor  $C_c$ . 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 shown in fig 4. The voltage stress on the switches ( $S_1, S_2, \dots S_n$ ) is decided by this clamp-capacitor voltage. It can be suggested that any other converter, which can perform similar boost operation

while maintaining the voltage level of the clamp capacitor can be also used for the active-clamp operation

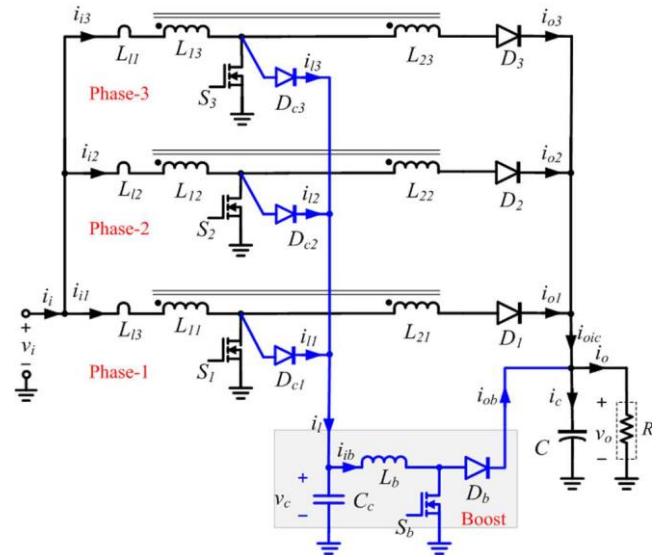


Fig. 4 Interleaved Coupled-Inductor Boost Converter with Single Boost Converter Clamp

### III. PROPOSED INTERLEAVED COUPLED-INDUCTOR BOOST CONVERTER WITH SINGLE BOOST CONVERTER CLAMP UNITS

In the practical coupled inductors, due to the non ideal coupling between the primary and the secondary windings, there will be leakage inductances. The equivalent circuit diagram of a practical converter with the leakage inductance is shown in Fig. 5

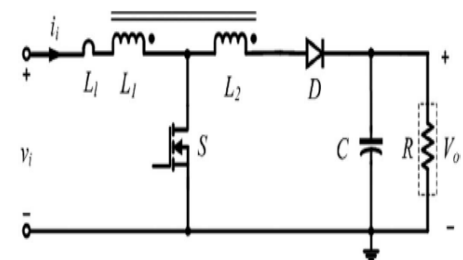


Fig. 5. Non ideal coupled-inductor boost converter with leakage inductance

This leakage inductance will can 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 shown in fig 6. 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.

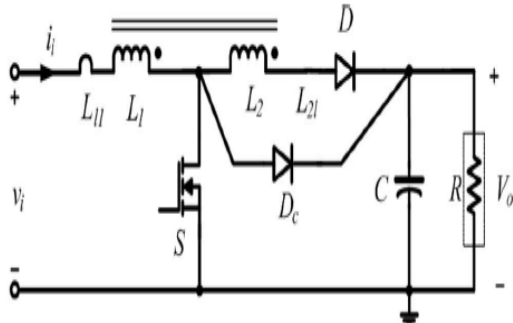


Fig. 6 Parallel diode clamped coupled-inductor boost converter

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 [5]. 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. To lower the voltage stress on the switches close to the level of the voltage stress present in an ideal coupled-inductor boost converter, a common active-clamp circuit based on a boost converter can be proposed as shown in Fig.7

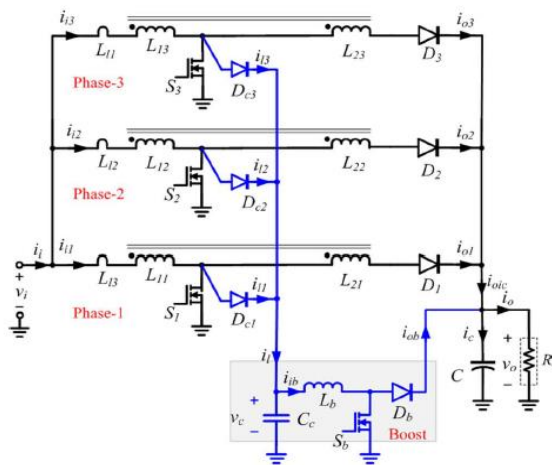


Fig7. .Proposed interleaved coupled- inductor boost converter with single boost converter clamp

In the proposed active clamp circuit, in each phase, a clamp-diode ( $D_{c1}, D_{c2}, \dots, D_{cn}$ ) is connected to the common node of the primary inductor, the secondary inductor, and the switch of an interleaved coupled inductor boost converter[5]. The cathode terminals of all the clamp diodes are connected to a clamp capacitor  $C_c$ . The energies stored in the leakage inductors of the interleaved phases are discharged through the clamp diodes and gathered in the clamp capacitor  $C_c$ . 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 shown in

Fig. 3 The voltage stress on the switches ( $S_1, S_2, \dots, S_n$ ) is decided by this clamp-capacitor voltage[3]. It can be seen 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.

#### IV. SIMULATION OF INTERLEAVED DC-DC CONVERTER

##### A. Conventional Coupled Inductor

This chapter deals with modeling of An Efficient High-Step-Up Interleaved DC-DC Converter with a Common Active Clamp. This converter is model using blocks of simulink and results are presented Figures

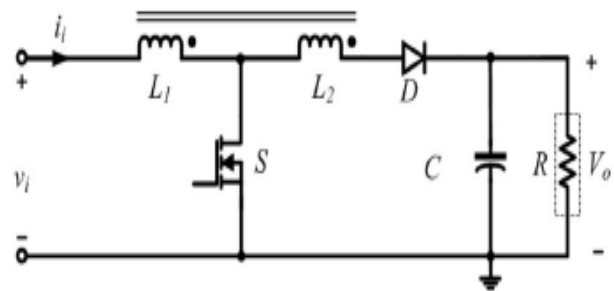


Fig. 8 Coupled inductor boost converter

##### B. Simulation of Conventional Coupled Inductor

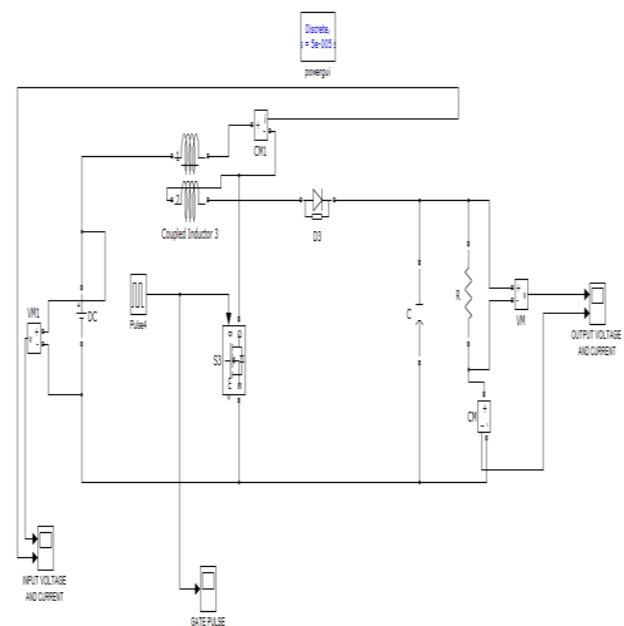


Fig. 9 Simulation of coupled inductor boost converter

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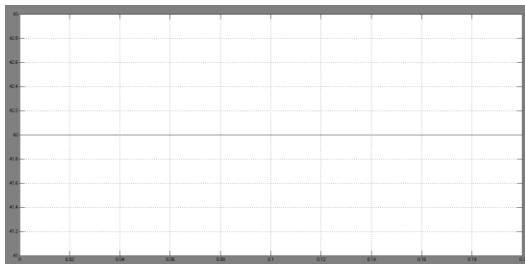


Fig. 10 Input Voltage of Coupled Inductor Boost Converter

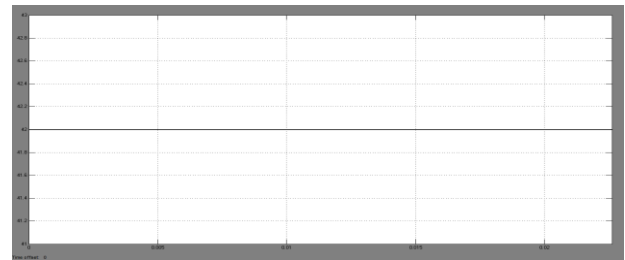


Fig. 14 Input Voltage of Coupled Inductor Boost Converter

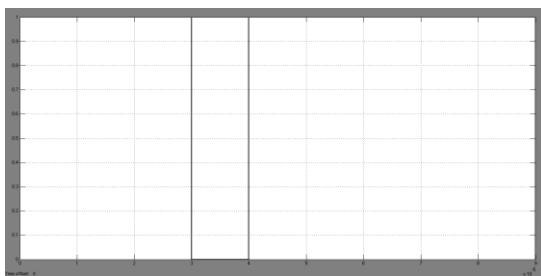


Fig. 11 Gate Pulse to Coupled Inductor Boost Converter

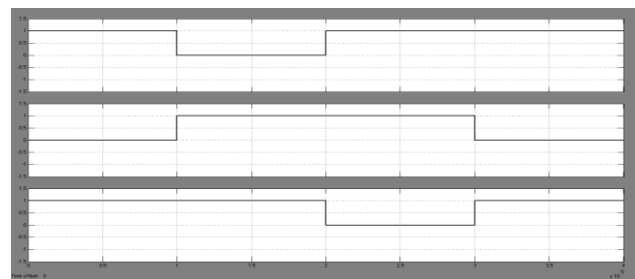


Fig. 15 Gate Pulse of Interleaved Coupled Inductor

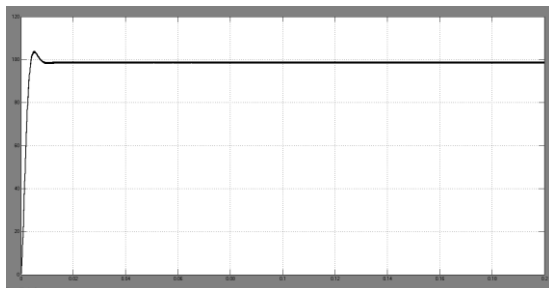


Fig. 12 Output Voltage of Coupled Inductor Boost Converter

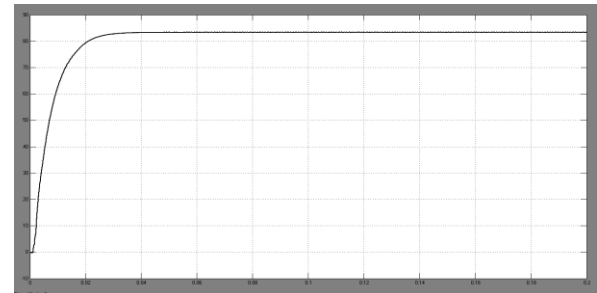


Fig. 16 Output Voltage of coupled Inductor

### C. Simulation of interleaved coupled-inductor

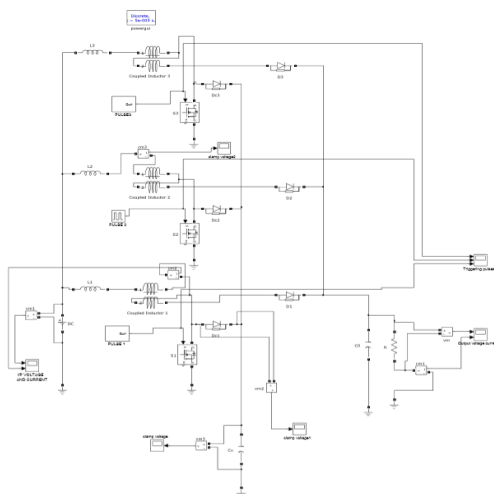


Fig. 13 Simulation of interleaved coupled inductor

### D. Simulation of interleaved coupled inductor boost converter

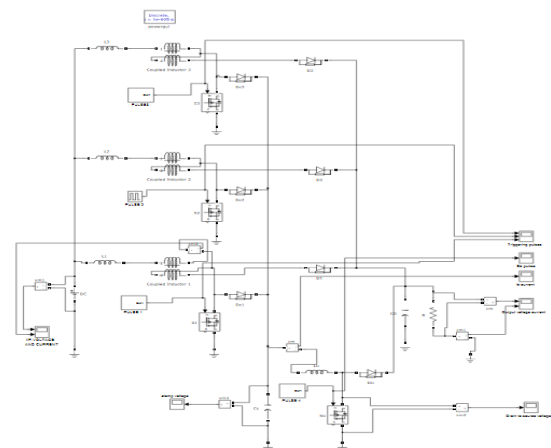


Fig. 17 Simulation of interleaved coupled inductor boost converter

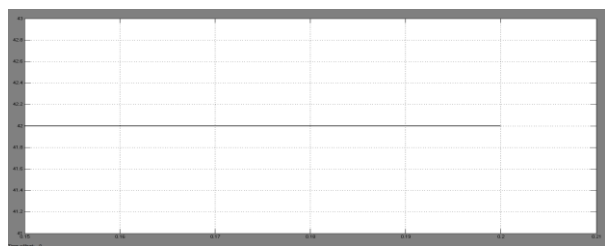


Fig. 18 Input Voltage Of Interleaved Coupled Inductor Boost Converter

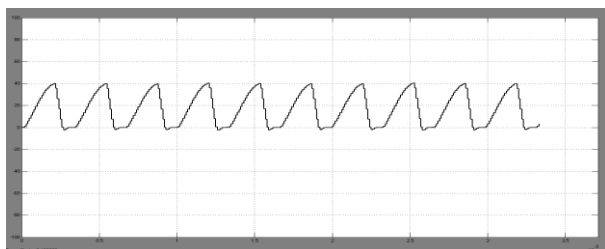


Fig. 19 Inductor Current Interleaved Coupled Inductor Boost Converter

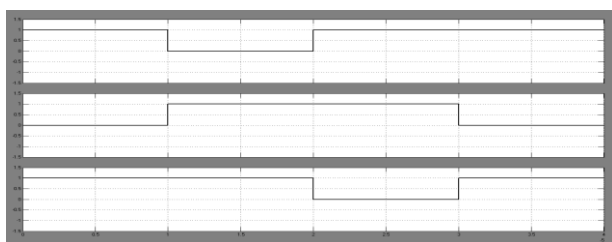


Fig. 20 Gate Pulses Switches Of Interleaved Coupled Inductor Boost Converter

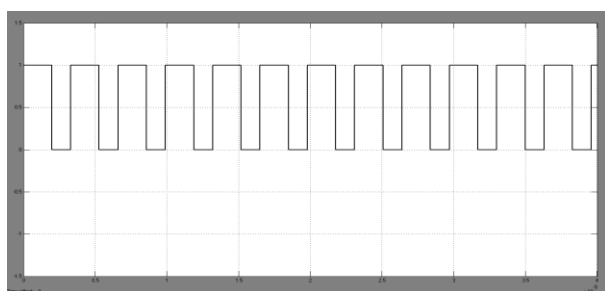


Fig. 21. Gate Pulse of Clamp Boost Converter

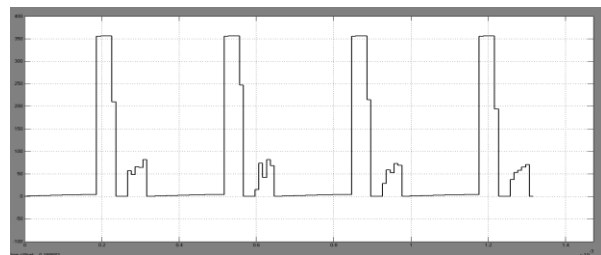


Fig. 22 Drain To Source Voltage Interleaved Coupled Inductor Boost Converter

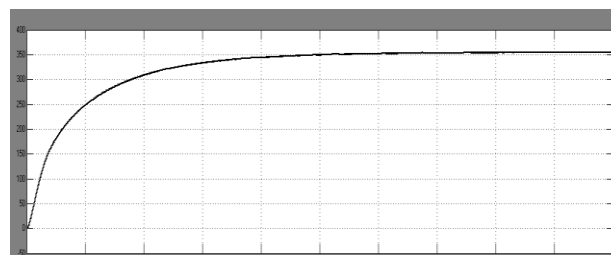


Fig. 21 Clamping Output Voltage Of Interleaved Coupled Inductor Boost Converter

## V. CONCLUSION

The project has proposed 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 non ideal 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. The coupled inductor boost converter reduces the voltage stress, current ripples and improves efficiency by recycling the leakage inductance.

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