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Implementation of an Interleaved High-Step-Up Dc-Dc Converter with A Common Active Clamp

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ABSTRACT: *This paper proposes a coupled inductor boost converter are interleaved with a common active clamp circuit is used for high power applications such as hybrid electric vehicles (HEV) electric vehicles (EV) and fuel cell vehicles (FCV). In a practical coupled inductor there will be considerable amount of leakage inductance present in interleaved converter. A single active clamp circuit can be proposed, in which the energy stored in leakage inductance of all the interleaved converters are collected in a clamp capacitor and recycled to the output by the clamp boost converter. This converter achieves high efficiency because recycling the leakage energies, reduction of switch voltage stress, mitigation of the output diode's reverse recovery problem and interleaving of the converters. The circuit will be simulated using MATLAB Simu-linK .*

Keywords — *Active clamp, boost converter, high voltage gain, hybrid electric vehicles (HEV), interleaving*

I. INTRODUCTION

Many applications powered by batteries call for high performance, high voltage step-up dc-dc converters. As an example for hybrid electric vehicles (HEV), electric vehicles (EV) and fuel cell electric vehicles (FCV). It can be noted that in all these applications, the high-voltage step-up dc-dc converters can be non isolated but they should operate at high efficiency while taking high currents from low-voltage dc sources at their inputs.

In a conventional boost converters cannot provide such a high dc voltage gain, even for an extreme duty cycle. It also may result in serious reverse recovery problems and increase the rating of all devices. As a result, the conversion efficiency is degraded and the electromagnetic interference (EMI) problem is severe under this situation.

The coupled inductor boost converter can be a good solution to the previously discussed problems of the conventional boost converter. This is because the turn's ratio of the primary inductor (L_1) to the secondary inductor (L_2) of the coupled inductor can be effectively used to reduce the duty ratio and the voltage stress of the switch. Therefore, for high-voltage step-up applications, the coupled inductor boost converter can be more efficient than the conventional boost converter. However, for high power applications, handling of very large input currents from the low-input voltage sources. Various converter topologies using magnetically coupled inductors are reported in the literature to reduce to extreme duty ratio operation. 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 achieve high efficiency and high reliability with reduced size inductors and capacitors.

In a practical coupled inductor, there will be considerable amount of leakage inductance present due to the non ideal coupling between the primary inductor (L_1) and the secondary inductor (L_2). The leakage inductance causes high voltage stresses to the switches, large switching losses, which degrade the converter performances. Resistor-capacitor-diode (RCD) based snubber circuits can be used to mitigate the problem, but the losses in these circuits are very high. Active-clamp circuits can be used address this issue. But these clamp circuits are complex and costly. Moreover, the efficiency improvement in these circuits is limited by the high conduction loss in the active- clamp switches. A single active clamp circuit can be proposed, in which energy stored in leakage inductances of all the interleaved coupled inductor boost converter are collected in a common clamp capacitor. In each of the interleaved units, a clamp diode is connected from the common node of the coupled inductors to the clamp capacitor for providing the discharge path of the leakage energy. Therefore, only the leakage currents flow through the clamp diodes; this makes the clamping operation efficient. A simple boost converter is controlled to keep the clamp capacitor voltage to a low level, and hence the voltage stress on the switches is low. This allows the use of low voltage and high performance devices.

This paper is organized as follows. Section II presents the coupled inductor boost converter and their interleaving. Section III presents the proposed interleaved coupled inductor boost converter with a common clamp boost converter. Detailed analysis of the converter is presented in this section and Simulation results are provided in Section IV. Section V concludes the paper.

II. COUPLED INDUCTOR BOOST CONVERTER AND INTERLEAVING

In high current and high power applications interleaved coupled inductor boost converter can be used. In this approach, a single coupled inductor boost converter cell is treated as a phase and n such phases are connected in parallel and operated at the same frequency. Furthermore, all the phases are operated at the same duty ratio, but they are phase shifted by $\mathbf{2^{\pi} / n}$ radian electrical angle (refer Fig. 1; n = 3). It can be mentioned that due to interleaving, the effective switching frequency as seen by the input and the output of the interleaved converter circuit is n times higher than the switching frequency of a phase. Under normal or full load condition, each of the interleaved phases equally shares the total output load. But under lower output power demand condition, the number of operating phases can be adjusted for maximum efficiency operation of the individual phases. The number of parallel phases ***n*** in an interleaved converter mainly depends on the maximum power demand of the load and maximum power rating of the interleaved phases.

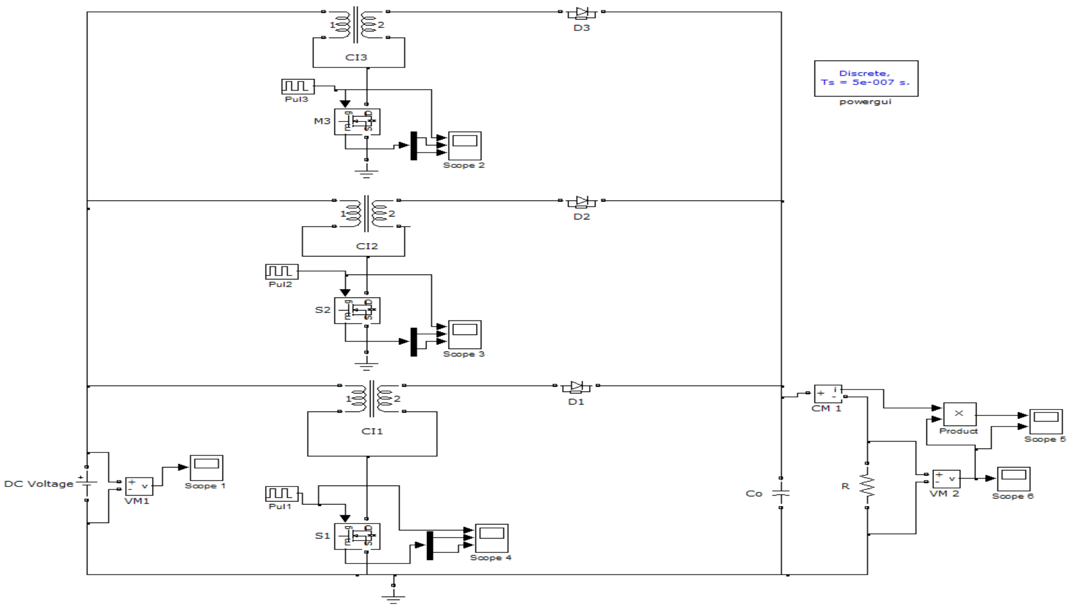

Figure 1: Three phase interleaved converter with ideal coupled inductor boost converters

The input voltage is given to the converter is 48 v dc.

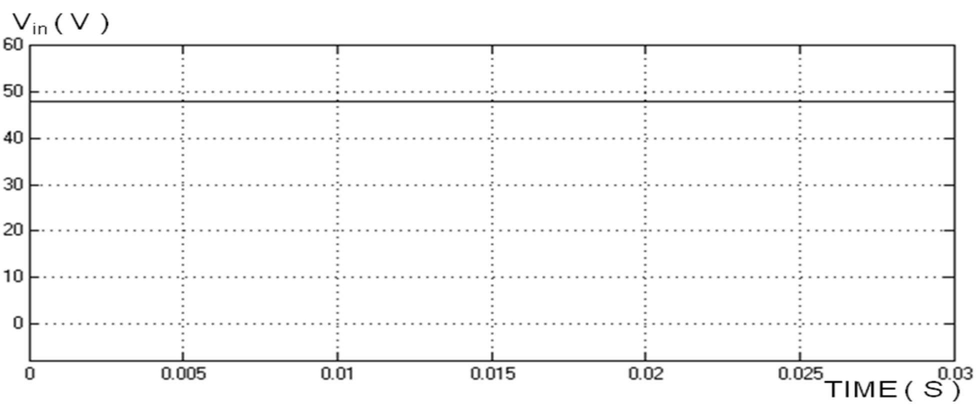

Figure 2: Input voltage

The output power is 900 W. The output voltage is higher value which is 310 V. The output voltage does not change with the change in time.

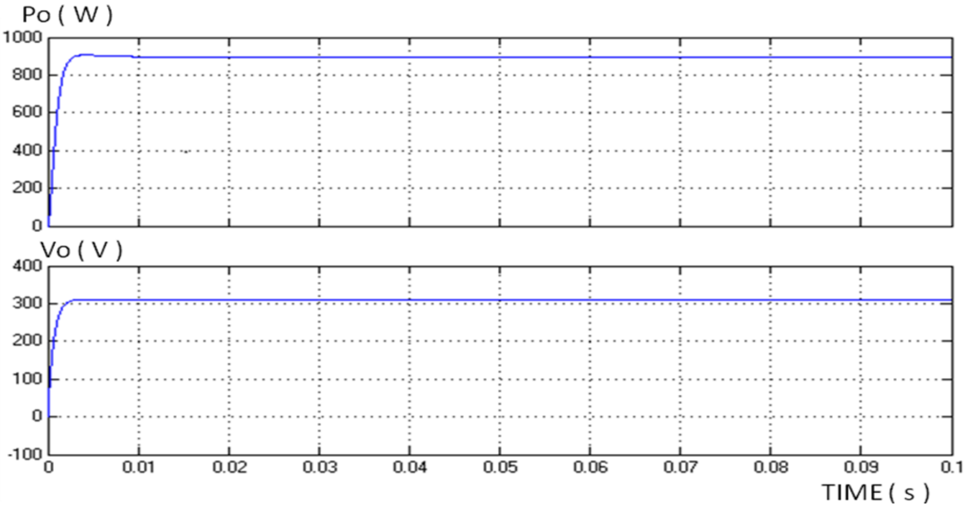

Figure 3: Output power and Output voltage

III. INTERLEAVED COUPLED INDUCTOR BOOST CONVERTER WITH A COMMON ACTIVE CLAMP

In practical coupled inductors, due to the nonideal coupling between the primary and the secondary windings, there will be a leakage inductances. The equivalent circuit diagram of a practical converter with leakage inductance is shown in Fig.4. This leakage inductance will cause high voltage spikes when the switch is turned off. The results in a high voltage stress across the switches. It can be proposed to clamp the switch voltage to the output voltage, using a parallel diode. 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.

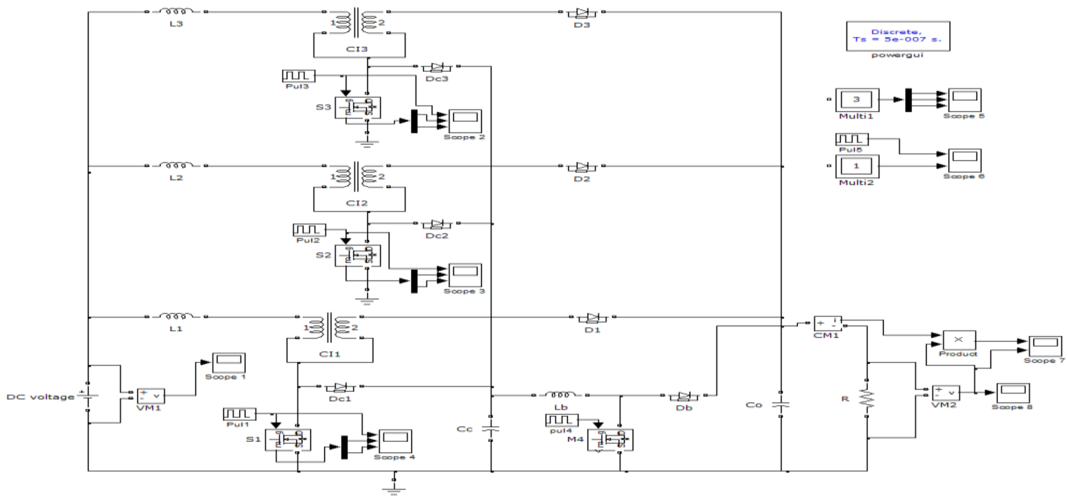

Figure 4: Proposed interleaved coupled inductor boost converter with single boost converter clamp

In proposed active clamp circuit, in each phase a clamp diode 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. The energies stored in the leakage inductors of the interleaved phases are discharged through the clamp diodes and gathered in the clamp capacitor. Furthermore, the boost converter is used to transfer the stored energy in the clamp capacitor to the output of the interleaved converters.

3.1 CONVERTER OPERATION

The proposed converter nonideal coupled inductor boost converters are operated under continuous conduction mode and a boost converter is used for active clamping of the interleaved converters. Under this condition, there are mainly three modes of operation in one switching cycle of coupled inductor boost converter. The operation modes for one of the interleaved phases are shown in Fig.5. The nonideal coupled inductors of the interleaved phases can be modeled by the magnetizing inductor (L_m), which is connected in parallel with an ideal transformer and a series leakage inductor (L_l). The turns ratio of the transformer is equal to the primary to the secondary turns ratio (1: N) of the coupled inductor.

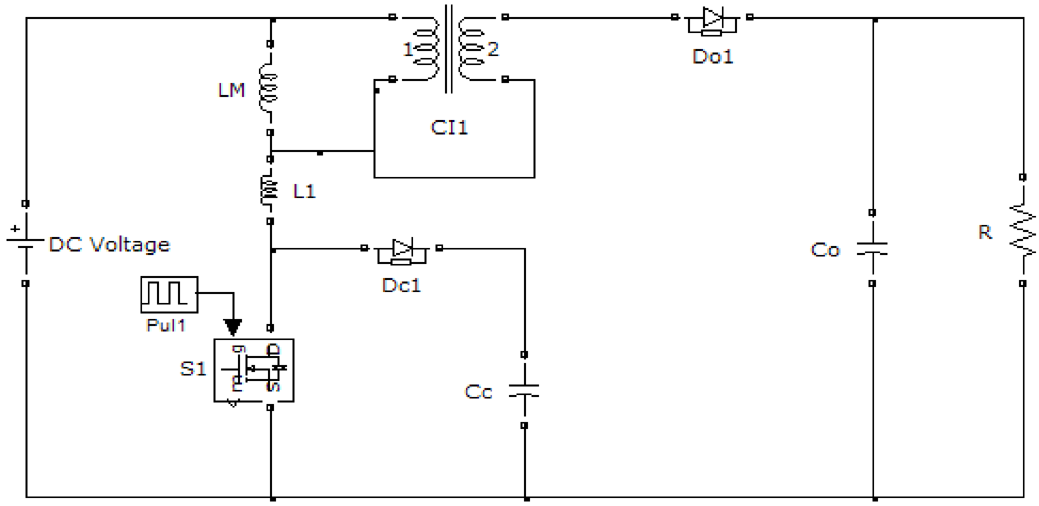

Figure 5: Parallel diode coupled – inductor boost converter

MODE - 1

This mode starts when the switch S_1 is turned on. The output diode D_1 and clamp diode D_{c1} is reverse biased. The input voltage V_i charges the magnetizing inductor and leakage inductor so input current increases.

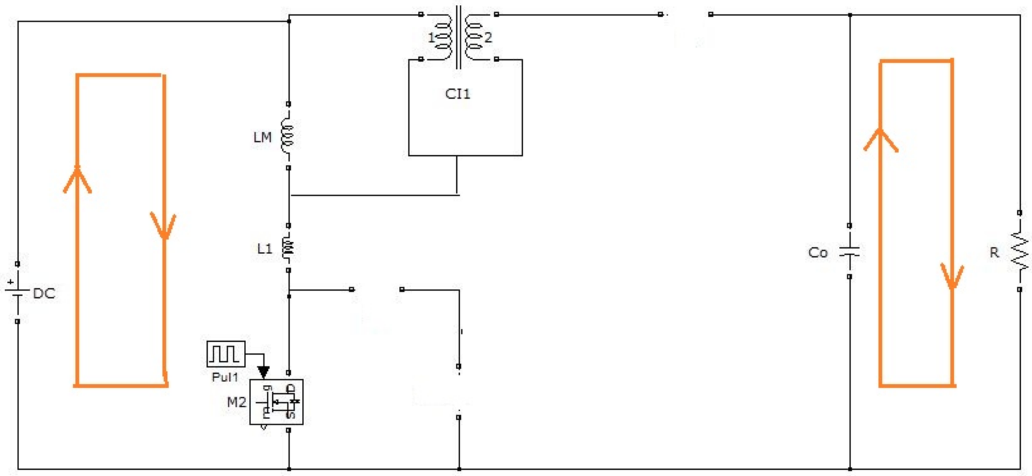

Figure 6 : Mode – 1 Circuit

MODE - 2

This mode begins when the switch S_1 is turned off. The leakage inductor forward biases the clamp diode, and magnetizing inductor forward biases the output diode which rises the output current. So energy stored in the leakage inductor is discharged to the clamp capacitor C_c. This causes a discharge current spike. The peak of this current is equal to the maximum value of the input current reached at the end of the Mode – 1.

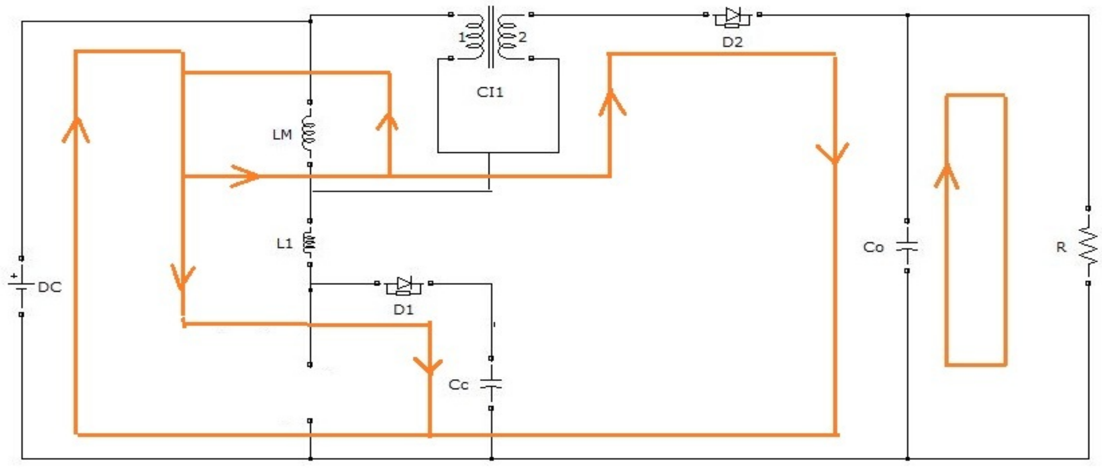

Figure 7 : Mode – 2 Circuit

MODE – 3

This mode starts when the leakage energy is completely discharged. The clamp diode is reverse biased by the clamp voltage V_c. The output diode remains forward biased. The energy to the output is transferred from the magnetizing inductor and from the source. The switch S_1 is remains turned off.

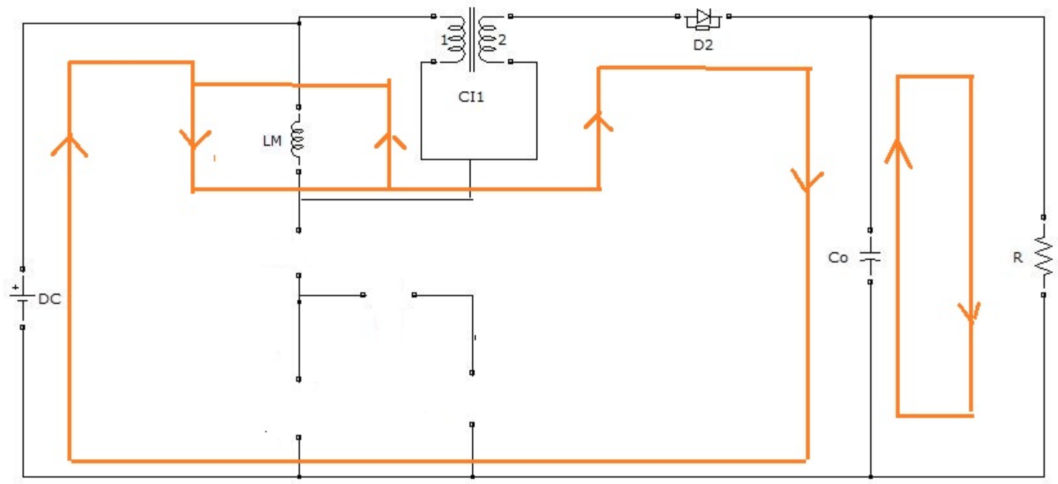

Figure 8 : Mode – 3 Circuit

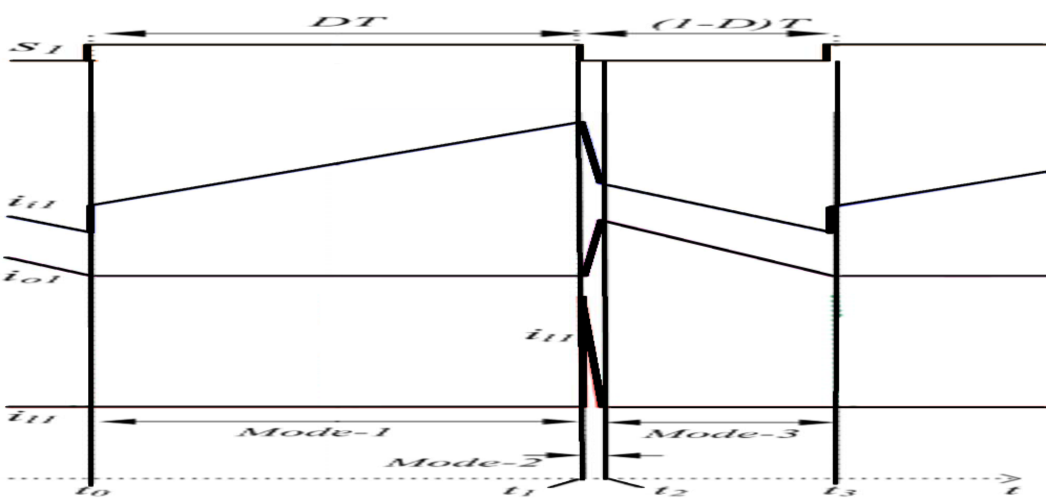

Figure 9 : Waveforms during the operation modes

3.2 CLAMP BOOST CONVERTER

The clamp boost converter is transfers the leakage energy stored in this clamp capacitor to the output and maintains its voltage to a desired clamp voltage level. So the power rating of the clamp boost converter is decided by the maximum total leakage energy of the interleaved converters. In this clamp boost converter has a fixed output voltage, but a variable input voltage. This is because the total leakage energy of the interleaved converters is very small compared to the total output power of the interleaved converters.

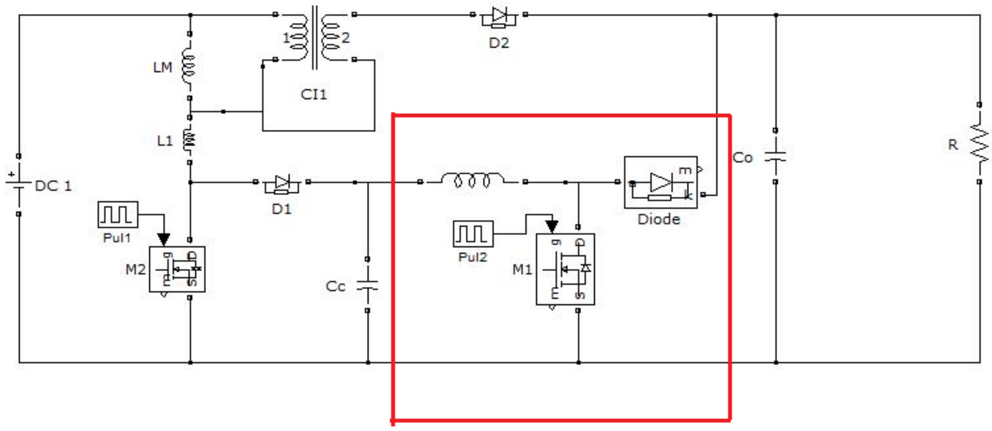

Figure 10 : Coupled inductor with clamp boost converter

IV. SIMULATION RESULTS

The simulation circuit of the proposed converter is shown in Fig.4. The input voltage is given to the converter is 48V. There are three interleaved phases are connected in parallel and operated in the same switching frequency is 25KHz. Furthermore, all the phases are operated at the same duty ratio is 0.66 but they are phase shifted by 120^0.

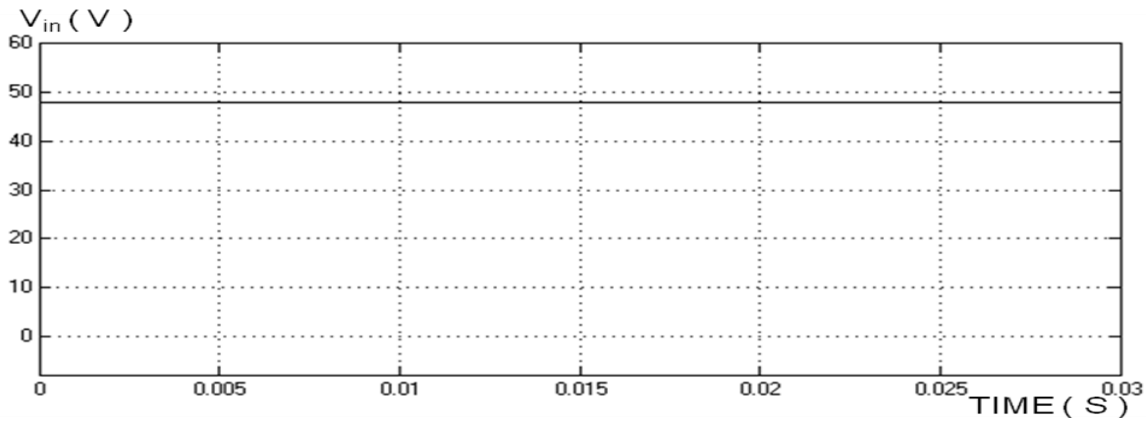

Figure 11 : Input Voltage

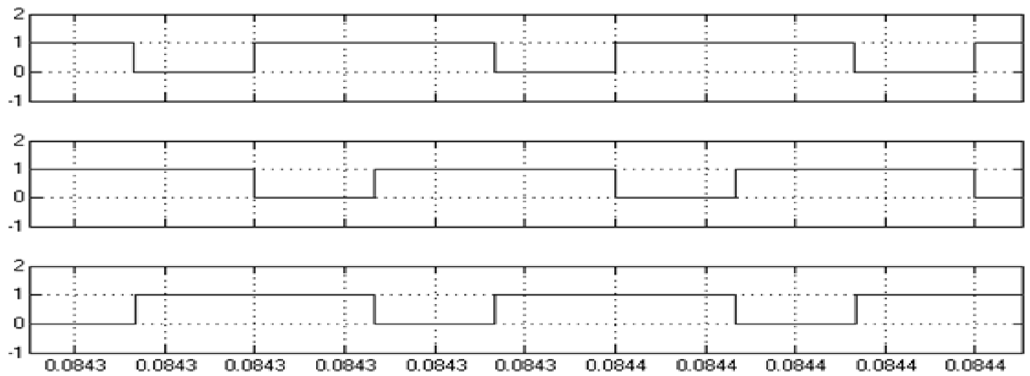

Figure 12 : Gate pulses to the proposed converter

The input currents of the interleaved coupled inductor boost converters are shown in Fig.14.The total input current of the converter is shown in Fig.13. It is measured the average value of the input current is 37.5 A.

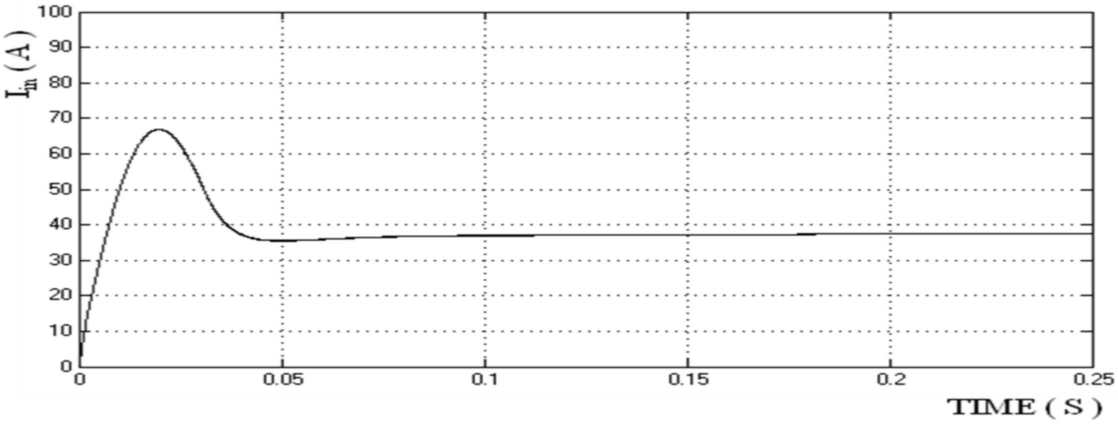

Figure 13 : Total input current of the converter

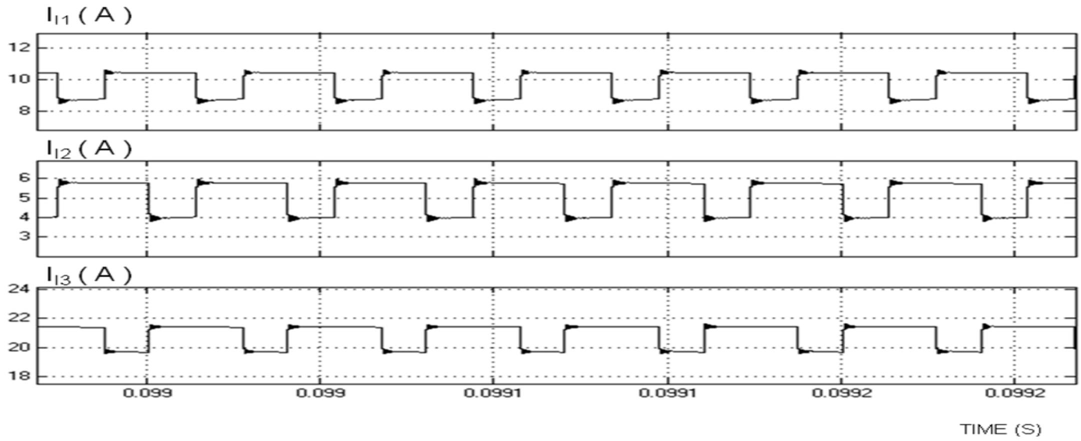

Figure 14 : Current through the leakage inductor

The gate pulses to the MOSFET of the clamp boost converter and the inductor current in that converter are presented Fig.15. When the switch is turned on .The input current rises and switch is turned off the inductor current falls until switch is tuned on again the next cycle.

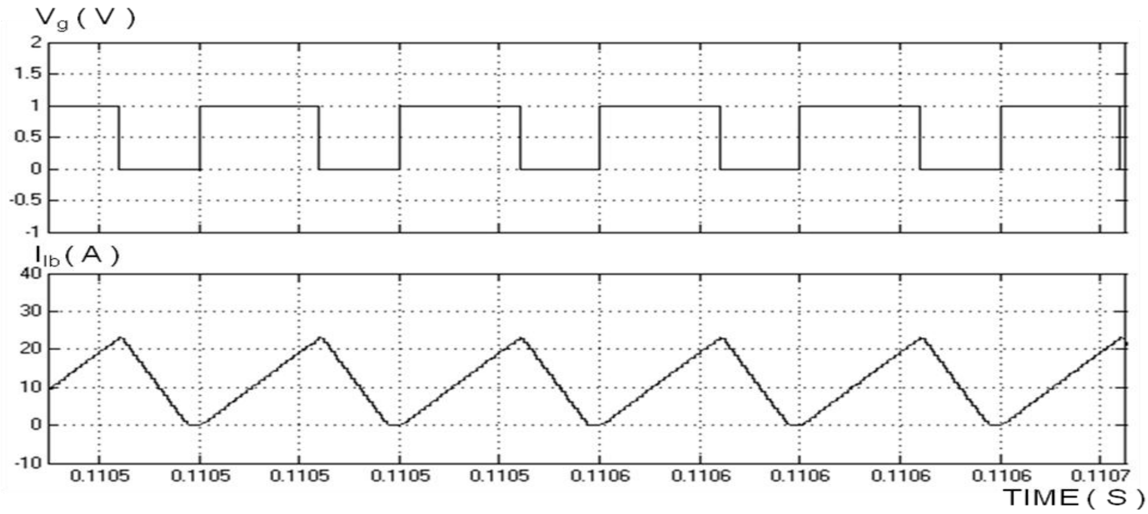

Figure 15 : Gate pulses and inductor current to the clamp boost converter

The output current is dc having a magnitude of 3.75 A. The output current does not change with the change in time.

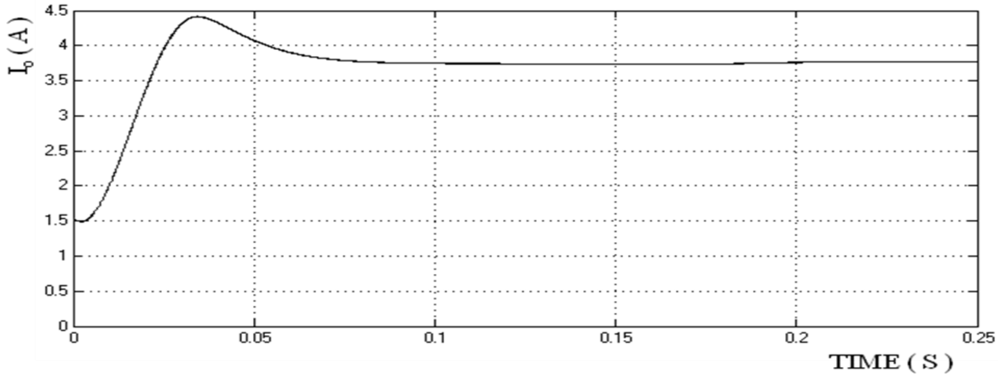

Figure 16 : Output current

The proposed converter boosts the input voltage of 48 V to the output voltage of 400 V. The output current is 3.75 A and the output power is 1500 W.

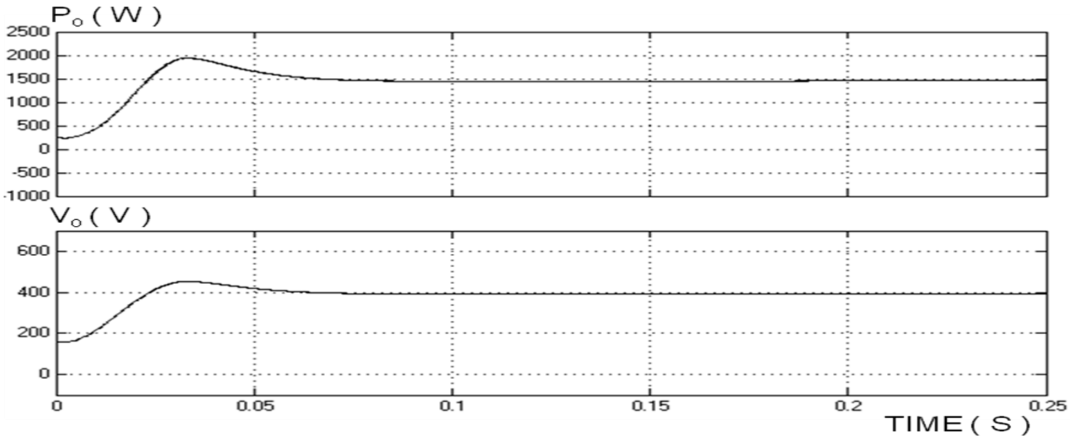

Figure 17 : Output power and output voltage

V. CONCLUSION

In this paper interleaved coupled inductor boost converter with common active clamp circuit is used for high current and high power application has been 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 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 paper. 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. Moreover, this converter was verified by the simulation results.

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