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A Parallel Input Series Output DC/DC Converter with High Voltage Gain

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Abstract - *The importance of high voltage gain dc/dc converter is increasing day by day. Conventional boost converter is unable to provide high gain without extreme duty ratio. An input parallel output series boost converter can provide a high step up gain. The converter uses two switches, two coupled inductors and a voltage multiplier module. The primary windings of coupled inductors are placed across the supply. Their connection reduces the input current ripple as it is shared by windings. The converter has high voltage gain and low voltage stress across power switches. The switches are turned on at zero current due to the leakage inductance of coupled inductor .The simulation of the converter is done in MATLAB/SIMULINK and results are obtained.*

Key Words: **High step up gain, DC/DC converter, Low voltage stress, Coupled inductors**.

1. INTRODUCTION

High gain dc/dc converters are widely used in many industrial applications such as solar, fuel cell, x-rays, laser and high intensity discharge lamp ballasts for automobile headlamps[2]-[4]. Theoretically, a basic boost converter is capable of providing high conversion ratio, but extremely high duty ratio is required. In practice, extreme duty ratios are not permitted because of the large conduction losses and frequent damage of power switches. Usually it is preferable to use low voltage rated power switches having low on state resistance to reduce the conduction losses, which may not be possible in a conventional boost converter. Cascaded boost converters can provide high voltage gain[5]-[6]. But high voltage stress across the switches and poor efficiency are the disadvantages. DC/DC converters using coupled inductors is a good alternative to obtain a high step up gain[7], provided the leakage inductances are handled properly. Interleaved control is found very useful in reducing the input current ripple of the converter[8]-[10]. Two different boost converter structures can be combined to produce twice the voltage gain by connecting there inputs in parallel and output in series. The two independent inductors of this combined converter is replaced by two coupled inductors. Connecting the primary windings of coupled inductors in parallel and secondary windings in series a high step up DC/DC converter is derived. An input parallel output series boost converter with dual coupled inductors can be used for high step up and high power applications. The interleaved control adopted reduces the input current ripple considerably. This configuration inherits the merits of high voltage gain, low voltage stress across the power switches and low output voltage ripple. Also, the converter is capable to turn on the active switches at zero current and hence reduce switching losses.

2. PARALLEL INPUT SERIES OUTPUT DC/DC CONVERTER

2.1 Input parallel output series boost converter

The input parallel output series concept is explained in Fig -1 to 3. The basic boost converter topology is shown in Fig -1 and Fig -2 is another boost version with the same function in which the output diode is placed on the negative dc rail. Fig -3 is called a modified interleaved boost converter, which is an input-parallel and output-series configuration derived from two basic boost types. The derived converter has twice the voltage gain of a conventional boost converter, low output voltage ripple and low input current ripple due to interleaved control.

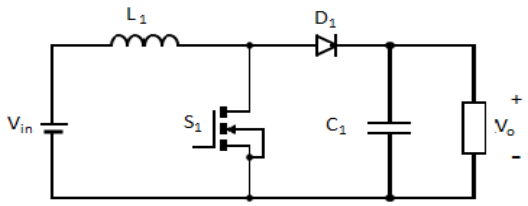

Fig -1:Boost converter type1

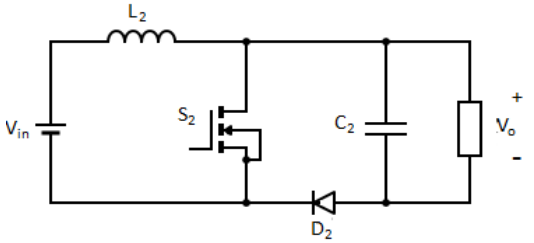

Fig -2: Boost converter type2

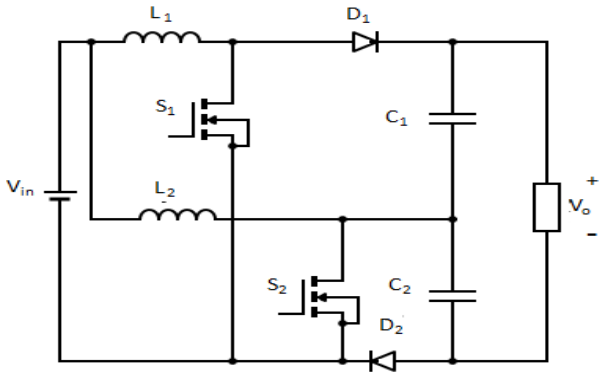

Fig -3: Parallel input series output DC/DC Converter

The separate inductors of Fig - 3 are modified by coupled inductors whose primary windings are connected in parallel and secondary windings in series as shown in Fig - 4. A voltage multiplier module is connected in the output to get a higher voltage gain. This connection has several advantages compared to conventional interleaved boost converter.

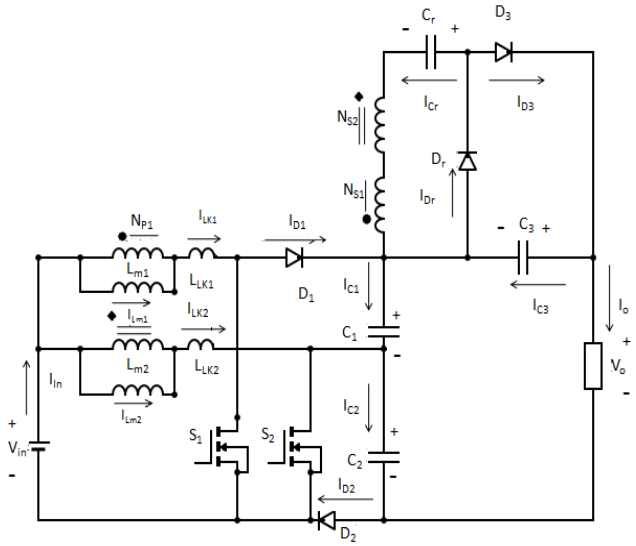

Fig -4: Input parallel output series DC/DC converter with high voltage gain

2.2 Operation of the converter

The converter is operated in continuous conduction mode(CCM). 180^0 interleaved overlapped pulses (Duty ratio greater than 50%) are used for the power switches. There are three switching states as S1 : ON, S_2 : ON; S_1 : ON, S_2 : OFF; S_1: OFF, S_2 : ON. Operation of the converter can be explained through eight modes in the above mentioned control scheme. The basic working principle is as explained below. The theoretical waveforms of the converter are shown in Fig -5. The schematic diagram in each operating mode is shown in Fig -6 to Fig -13.

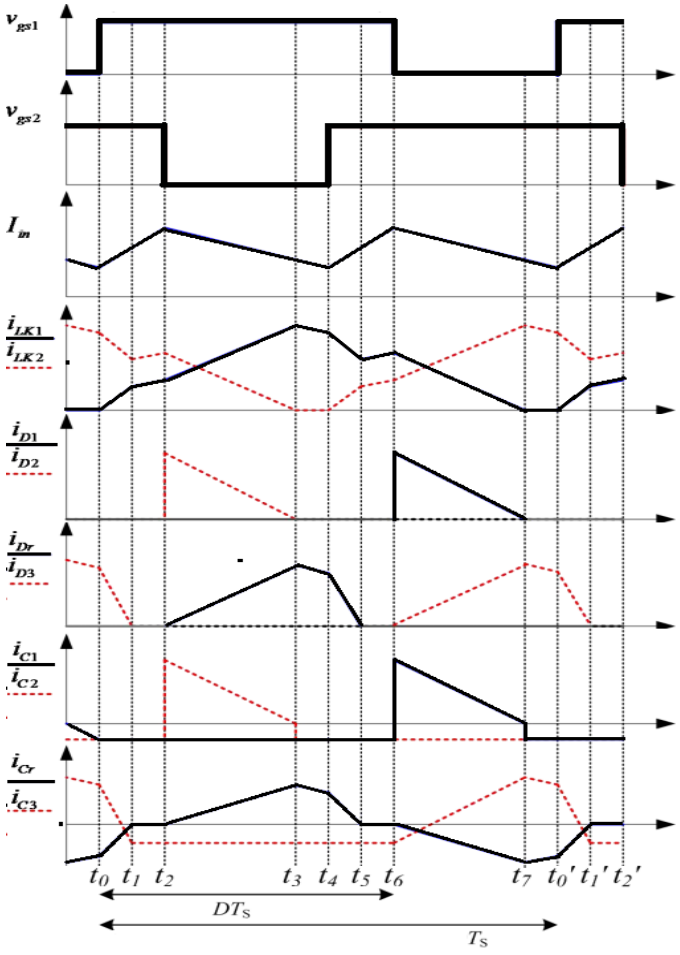

Fig -5: Theoretical waveforms

Mode 1[t_0-t_1]:- At t=t_0 Switch S_1 is turned on at zero current switching due to the leakage inductance of L_{K1} . S_2 remains turned on from the previous state as shown in Fig -6. All diodes except output diode D_3 is turned off. This phase ends when the current through D_3 decreases to zero.

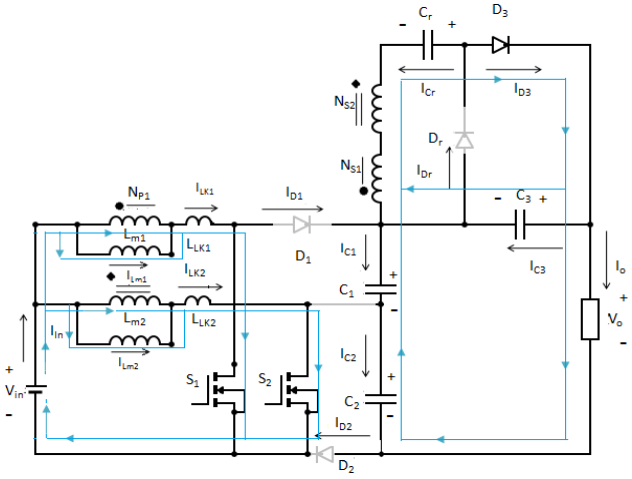

Fig -6: Mode 1

Mode 2[t_1-t_2]:- In this stage the power switches S_1 and S_2 remains turned on, as shown in Fig -7. All of the diodes are

reversed-biased. The voltage source V_{in} charges magnetizing inductances L_{m1} and L_{m2} as well as leakage inductances L_{k1} and L_{k2}. This stage ends at t_2, when S_2 is turned off.

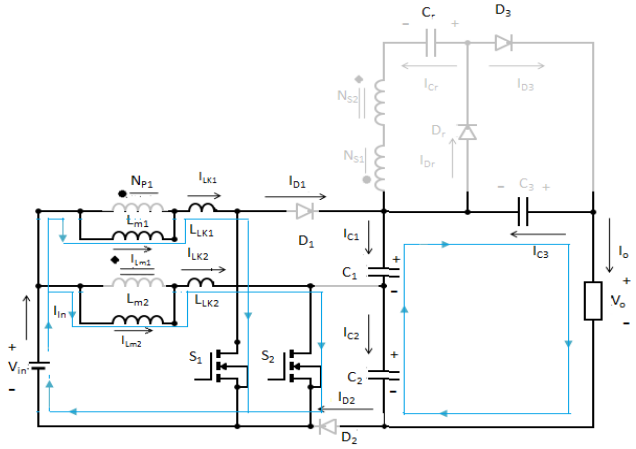

Fig -7: Mode 2

Mode 3[t_2-t_3]:- The switch S_2 is turned off at t = t_2, hence the diodes D_2 and D_r turned on. The current flow direction is shown in Fig -8. The energy that has stored in magnetizing inductance L_{m2} is transferred to the secondary side, charging the capacitor C_r through D_r. The input voltage source V_{in}, magnetizing inductance L_{m2} and leakage inductance L_{k2} deliver energy to the capacitor C_2 through diode D_2.

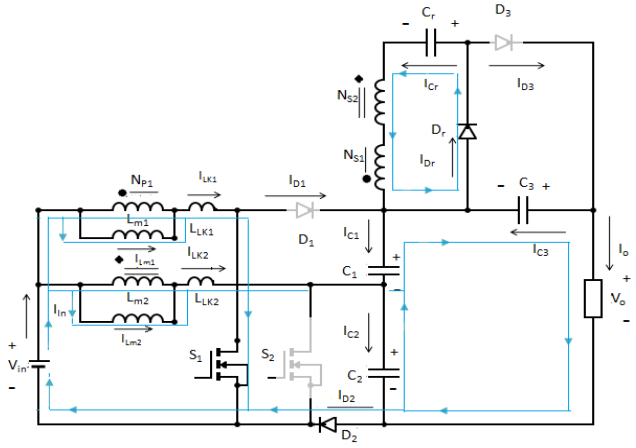

Fig -8: Mode3

Mode 4[t_3-t_4]:- when the total energy of leakage inductance L_{k2} has been completely delivered to the capacitor C_2 at t = t_3, diode D_2 automatically switches off. The current flow path of this stage is shown in Fig -8. Magnetizing inductance L_{m2} will transfer energy to the secondary side charging the capacitor C_r through diode D_r. The sum of currents of the magnetizing inductances L_{m1} and L_{m2} flows through the switch S_1.

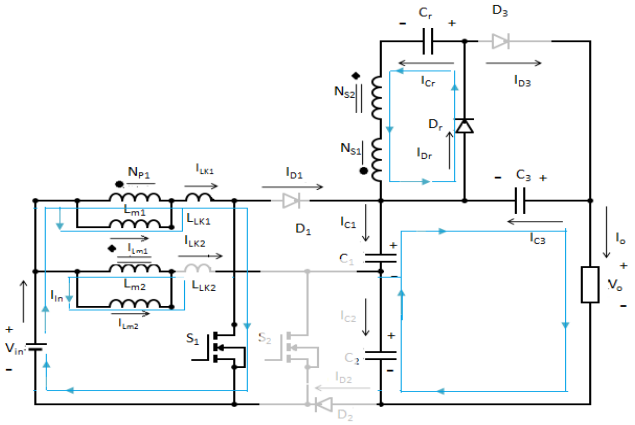

Fig -9: Mode 4

Mode 5[t_4-t_5]:- The switch S_1 remains turned on at t = t_4, the switch S_2 is turned on with ZCS due to the leakage inductance L_{k2}. The current flow direction of this stage is shown in Fig -10. This stage ends when the current through the diode D_r reduces to zero at t =t_5.

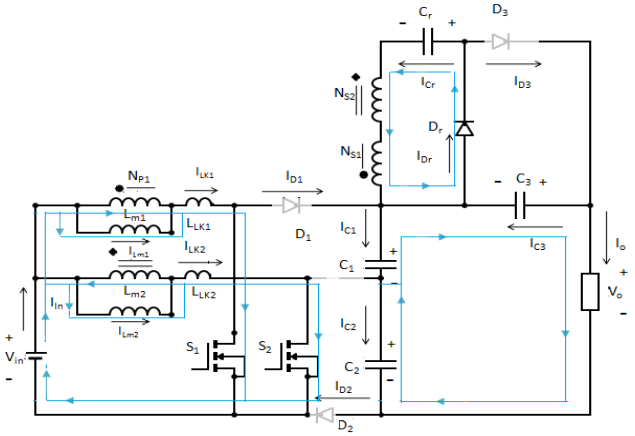

Fig -10: Mode 5

Mode 6[t_5-t_6]:- Operating modes 2 and 6 are same. All diodes are turned off. The magnetizing inductances L_{m1}, L_{m2}, and the leakage inductances L_{k1}, L_{k2} are charged by the source.

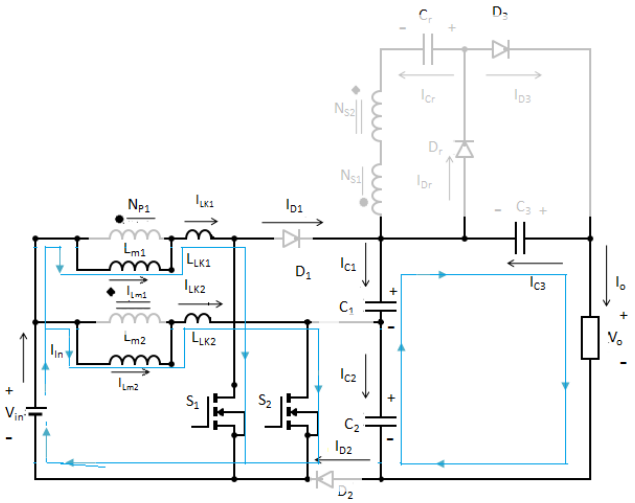

Fig -11: Mode 6

Mode 7[t_6-t_7]:- The switch S_2 remains turned on. Switch S_1 gets turned off at t = t_6. Which bring D_1 and D_3 into

conduction. The current flow path of this stage is shown in Fig -12. The source V_{in}, L_{m1} and L_{k1} together release their energy to the capacitor C_1 through the switch S_2. At the same time, the energy stored in L_{m1} is released to the secondary side. D_3 is conducting and the current through the secondary sides will flow to load and capacitor C_3.

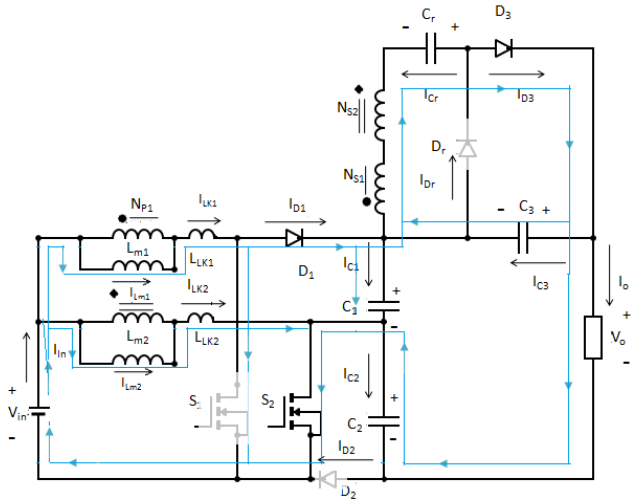

Fig -12: Mode 7

Mode 8[t_7-t_8]:- At time t = t_7, diode D_1 gets turned off because the total energy of leakage inductance L_{k1} has been completely transferred to the capacitor C_1. The current of the magnetizing inductance L_{m1} continues to flow to the output through the secondary side of coupled inductor and D_4 until t_0.

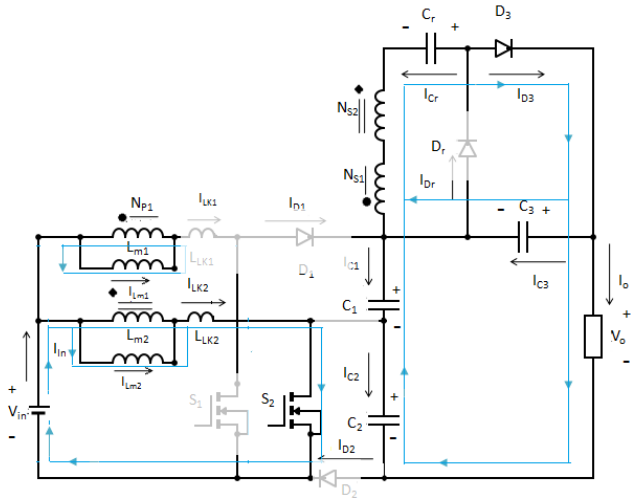

Fig -13: Mode 8

3. CIRCUIT ANALYSIS AND DESIGN

3.1 Voltage gain expression

Take two identical coupled inductors. Using the volt-second balance principle on magnetizing inductances L_{m1} and L_{m2} respectively, the voltage gain (m_{CCM}) can be obtained as, [1]

$$m_{CCM} = \frac{2(kN+1)}{1-D} \quad (1)$$

Where k is the leakage factor of coupled inductors, N is the turns ratio and D is the duty ratio.

3.2 Voltage stress analysis

To simplify the voltage stress analyses of the components, the leakage inductance of coupled inductor and the voltage ripples on the capacitors are ignored. The voltage stresses on power switches S_1 and S_2 for an output voltage V_0 are derived as, [1]

$$V_{S1} = V_{S2} = \frac{V_0}{2(1+N)} \quad (2)$$

3.3 Coupled inductor design

From the voltage gain equation, the turns ratio of coupled inductor can be designed as, [1]

$$N = \frac{m_{CCM}(1-D)}{2k} - \frac{1}{k} \quad (3)$$

3.4 Capacitor design

The filter capacitors are designed considering the voltage ripple(ΔV_C) across it, for switching frequency f_s and load resistance R the capacitor values are estimated according to below equations [1]

$$C_1 \geq \frac{DV_0}{\Delta V_{C1} R f_s} \quad (4)$$

$$C_2 \geq \frac{DV_0}{\Delta V_{C2} R f_s} \quad (5)$$

$$C_3 \geq \frac{DV_0}{\Delta V_{C3} R f_s} \quad (6)$$

$$C_r \geq \frac{V_0}{\Delta V_{Cr} R f_s} \quad (7)$$

2. SIMULATION AND RESULTS

The converter is simulated in MATLAB/simulink and simulation results are obtained. The simulink model of the converter is shown in Fig -14. The pulse generation circuit is shown as a subsystem. 180^0 interleaved overlapped pulses are used. The control signals with duty ratio 0.5 are shown in Fig -15. The simulation parameters are shown in table 1.

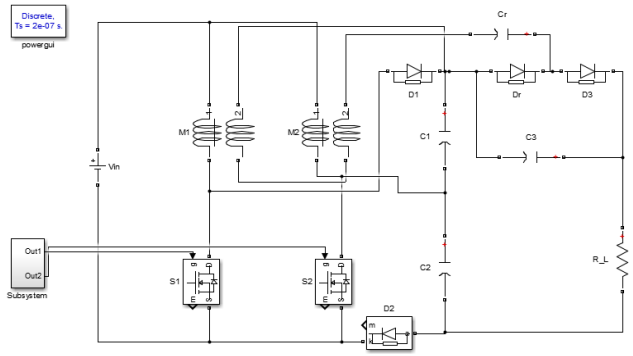

Fig -14: Simulink model IPOS high gain converter

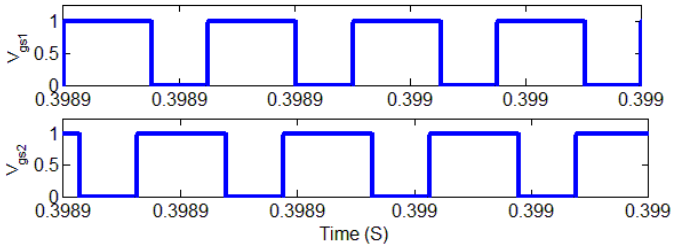

Fig -15: Control pulses of switches

Table -1: Simulation parameters.

Parameter	Value
P_o	100W
V_{in}	20
Magnetizing inductance, L_{m1},L_{m2}	242 µ H
Capacitors C_1, C_2	47 µ F
Capacitor C_3	100 µ F
Capacitor C_r	10 µ F
Switching frequency, f_s	40kHz
V_{out}	200

Fig - 16, 17 respectively shows the voltage across and current flowing through the switches 1 and 2. The voltage stress across the switch is a quarter of the output and switches are turned on at zero current.

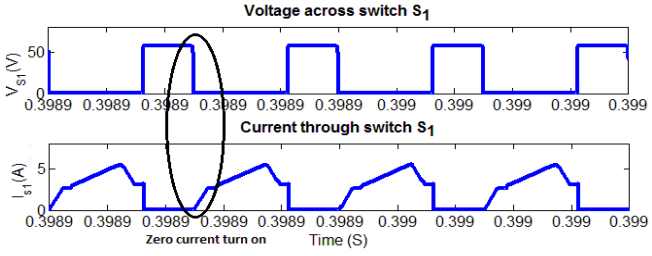

Fig -16: Soft switching of switch S_1

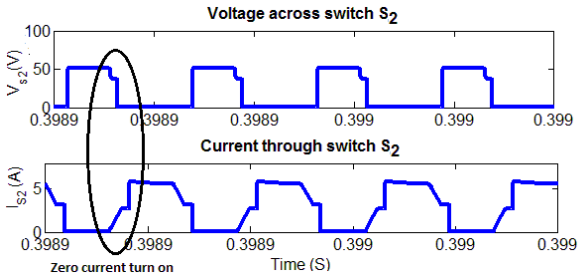

Fig -17: Soft switching of switch S_2

It is clear from the waveforms that the switches are turned on with zero current turn on due to the leakage inductance present in the path and hence switching losses are reduced.

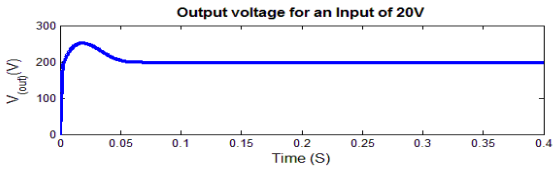

Fig -18: Output voltage waveform

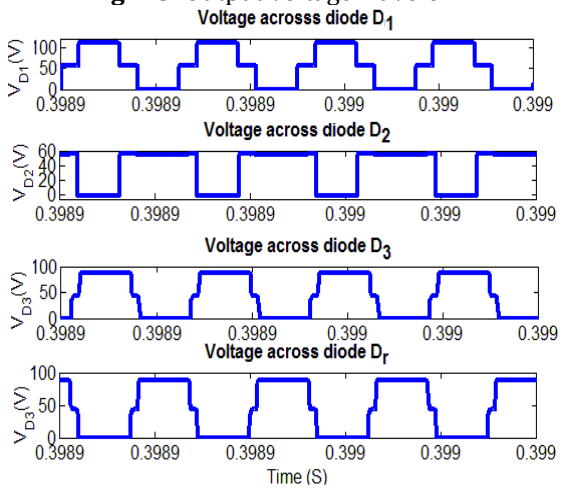

Fig -19: Voltage stress across diodes

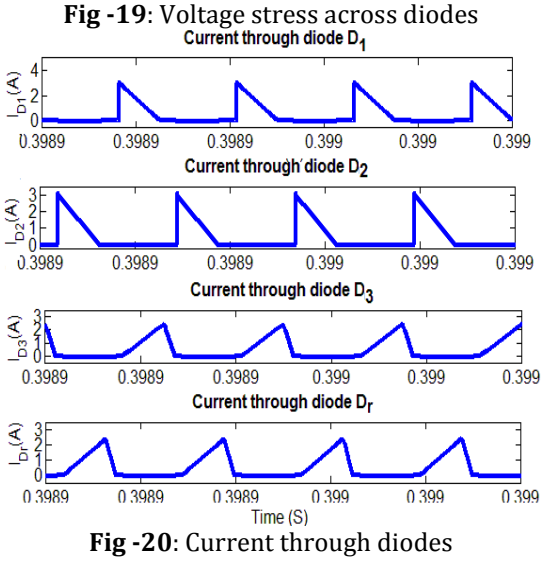

Fig -20: Current through diodes

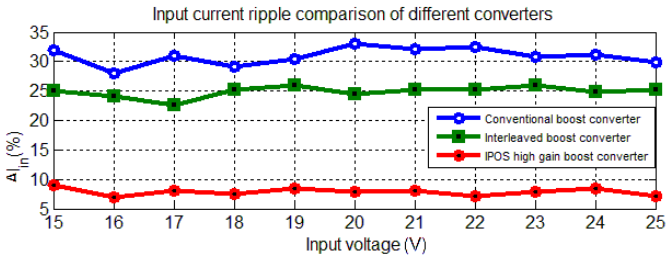

Fig -21: Ripple comparison

The output voltage with an input of 20V shown in Fig - 18 proves that the converter achieves the expected voltage gain with a low duty ratio of 0.6. Fig -19 and Fig -20 respectively show the voltage across and current flowing through the diodes. Ripple comparison shown in Fig -21 proves that the converter has a very less input current ripple compared to conventional boost/interleaved boost converter.

3. CONCLUSIONS

An parallel input series output DC/DC converter using dual coupled inductors is found to be a good candidate for low input voltage, high voltage gain applications. The converter can achieve a much higher voltage gain and avoid operating at extreme duty cycle and numerous turn's ratios. A voltage gain of 10 is obtained by operating at a duty ratio of 0.6 with turns ratio 1. The voltage stresses of the power switches are very low, which is 25% of the output voltage. Interleaved control reduces the input current ripple effectively. The output voltage ripple is calculated as 0.02%. The simulation results show that main switches can be turned on at zero current.

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