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# Current Ripple Reduction Using Two Inductor Boost Converter

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***Abstract*** *— Employing a new modified two inductor boost converter with current ripple reduction is presented in this report. It features are low voltage stress on the rectifier diode , high voltage gain with smaller transformer turns ratio , recovery of the transformer secondary leakage energy and low output current ripples . Therefore high power density and high power efficiency can be achieved . In addition to descriptions of the operational principle , mathematical analysis , and matlab simulation are done in this report .The performance comparison are made to demonstrate the superiority of two inductor boost converter over the single inductor boost converter and current fed center trapped transformer .*

***Keywords***- *Current Ripple Reduction , Lossless snubber ,Clamping Capacitor*

## I. INTRODUCTION

In recent years the fossil fuel supplies have experienced a shortage, which causes serious environmental problem. Therefore, developing a high efficiency renewable source of energy has become an urgent matter .But there is one problem is that the renewable energy source can't supply directly to dc or ac appliance due to wide range of low dc output voltage. So, boost converter is required for high dc output voltage. There are various step-up converter topologies classified with (1) Voltage fed configuration (2) Current fed configuration .

A large turns-ratio between the primary and secondary sides of the transformer is necessary for voltage fed step up DC-DC converter because only the winding ratio performs the voltage boosting function . So , the construction of such transformer introduces leakage inductance and large parasitic capacitances . Among various step-up converter topologies, the voltage-fed configuration can not use in high voltage application because of following reason, It require large capacitor to meet severe ripple current characteristics. Due to parasitic capacitances the high voltage and high current spikes on the power devices . In addition the voltage boosting function is only realized by using transformer but with large turn ratio, so due to this large capacitance & leakage inductance are induced. So, voltage fed configuration is highly constrained due to high voltage transformer & large input current ripple. Alternatively, current fed configuration is widely used for boosting application because of following reason, It has continuous input current resulting minimize the number of capacitor. Decreasing conduction loss. So, current fed configuration is preferred for the dc-dc boost converter topology over voltage fed configuration.[1],[4]

A full-wave rectification circuit & filter circuit are essentially required on the secondary side of transformer to generate high dc output voltage. But there are two main problem deal with this stages, The output current suffers from high current ripple due to absence of a output inductor And there are voltage spikes caused by transformer leakage inductance resulting in using high voltage rectifier diode. To alleviate the above mentioned problems , a full-wave rectifier circuit with output current ripple reduction is introduced in this paper. The operation principle , theoretical analysis & Matlab simulation are presented

## II. ANALYSIS AND CIRCUIT OPERATION

The circuit diagram & waveforms are shown in figure 3.1 and 3.2 . From figure we show that it comprises One transformer $T_r$ , Two input inductor $L_1$ & $L_2$ , One output capacitor $C_1$ , One clamped capacitor $C_0$ , and Two series connected diode pair $D_1$-$D_2$ & $D_3$-$D_4$. The transformer $T_r$ has One primary winding & Two secondary winding .

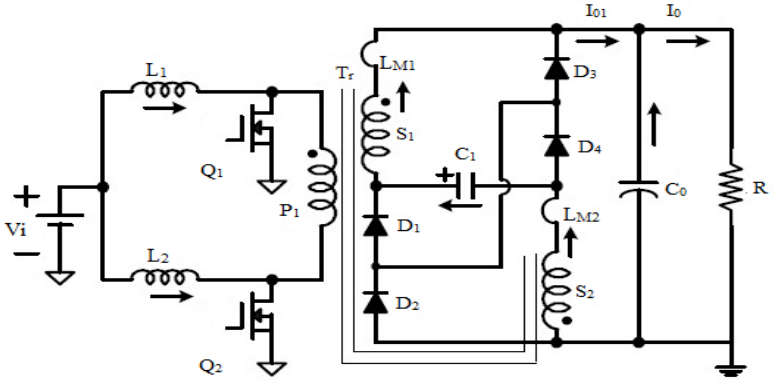


***Figure 1. Circuit Diagram Of Two Inductor Boost Converter***

The waveform of the Two inductor boost converter are as below ;

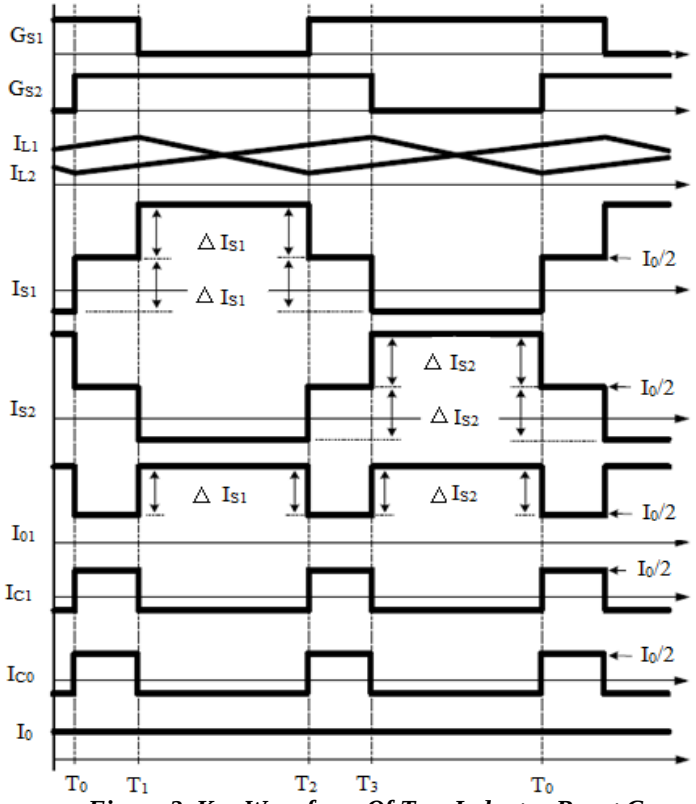



***Figure 2. Key Waveform Of Two Inductor Boost Converter***

Without C1 and the connection between two diode pairs, it is identical to the current-fed boost converter with center-tap rectifier (CF-CT). Two Inductor Boost Converter operation can be described by four stages shown in figures ,

A. **MODE - I [$T_0$-$T_1$]** :-

Fig 3 (a) show the , gate pulse applied to switch $Q_2$ to control that at $T_0$ , and at that time both switch $Q_1$ & $Q_2$ are turned on. So , the inductor current $I_{L1}$ & $I_{L2}$ increased linearly at this interval $T_0$-$T_1$. The voltage across the transformer $T_r$ primary winding is shorted due to switch $Q_1$ & $Q_2$ on. So , due to shorted primary winding , the all diodes $D_1$ , $D_2$ , $D_3$ , $D_4$ are reversed biased & turn off. Show the figure , output capacitor $C_0$ due to providing this one half of the load current is provided by the clamping capacitor $C_1$ through $C_1$(+)-$S_1$-$L_{M1}$-R-$S_2$-$L_{M2}$-$C_1$(-). So , due to use of clamping capacitor $C_1$ the output current ripple $I_{C0}$ are reduced. Without clamping capacitor $C_1$ & the connection between two diode pairs it is identical to the current fed boost converter with center tap rectifier CF-CT.[6]

$$I_{S1} = I_{S2} = I_{01} = \frac{1}{2} I_0$$

$$I_{01} + I_{C0} = I_0$$

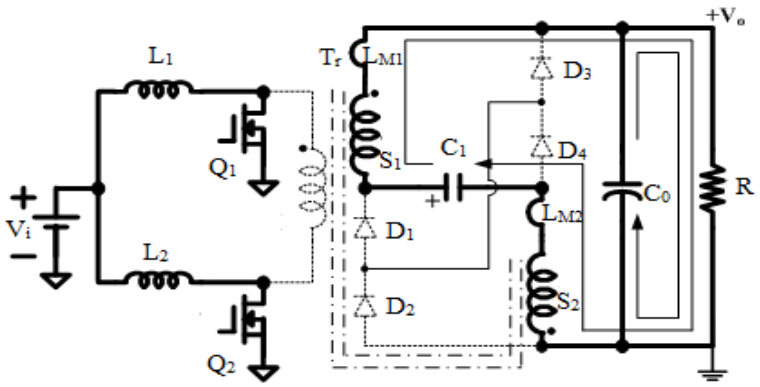



***Figure 3(a) MODE I [T0-T1]***

B. **MODE – II [$T_1$-$T_2$] :-**

Fig 3(b) show the, in this mode the switch [$Q_1$] is turned off at $T_1$. So ,the inductor current $I_{L1}$ decreased in this mode & inductor current $I_{L2}$ is increased linearly. So , the voltage across the transformer primary winding $P_1$ is the sum of the input source voltage $V_i$ & the inductor voltage. The input power is transferred to the load via transformer $S_1$ during this internal $T_1$-$T_2$. The input power which is used to charge the clamped capacitor $C_1$ & output capacitor $C_0$ through $S_2$-$D_2$-$D_1$-$C_1$-$L_{M2}$-S2and $S_1$-$L_{M1}$-$C_0$-$D_2$-$S_1$, respectively. In this mode the diode $D_1$ & D3 will be forward biased , so due to turning on the $D_1$ & $D_2$ , the voltage across $D_3$ , $D_4$ are clamped to $V_0$ and $V_{C1}$ , respectively.[6] The current maintain following equations ;

$$I_{S1} = I_{01} = \frac{I_0}{4} * \frac{2D-3}{D-1}$$

$$I_{S2} = I_{C1} = \frac{I_0}{4} * \frac{2D-1}{D-1}$$

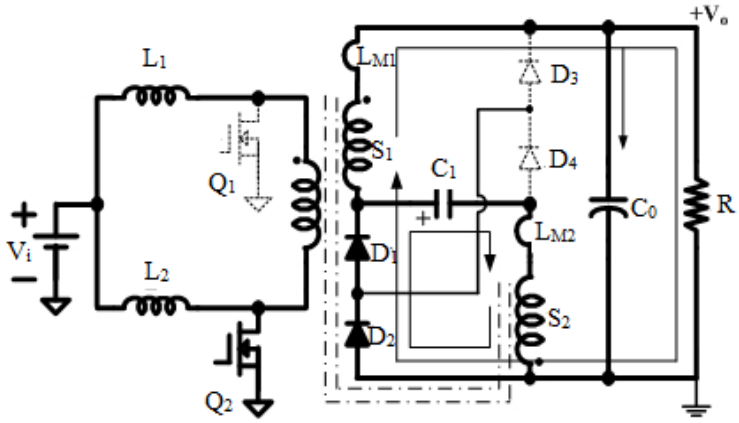



***Figure 3(b) MODE II [T1-T2]***

**C. MODE – III [$T_2$-$T_3$] :-**

Fig 3(c) show the , gate pulse applied to switch $Q_1$ to control at $T_2$ and at that time both switch $Q_1$ & $Q_2$ are turned on during this time interval. So , the inductor current $I_{L1}$ & $I_{L2}$ increased linearly at this internal ($T_2$-$T_3$). Again the voltage across the transformer $T_r$ primary winding is shorted due to switch $Q_1$ & $Q_2$ on. So , due to shorted primary winding , the all diodes $D_1$ , $D_2$ , $D_3$ , $D_4$ are reversed biased & turn off. Due to output capacitor C0 due to providing this one half of the load current is provided by the clamping capacitor C1 through C1(+)-S1-LM1-R-S2-LM2-C1(-). So , due to use of clamping capacitor C1 the output current ripple IC0 are reduced.[6] From figure we show that , the current maintain the following equations,

$$I_{S1} = I_{S2} = I_{01} = \frac{1}{2} I_0$$

$$I_{01} + I_{C0} = I_0$$

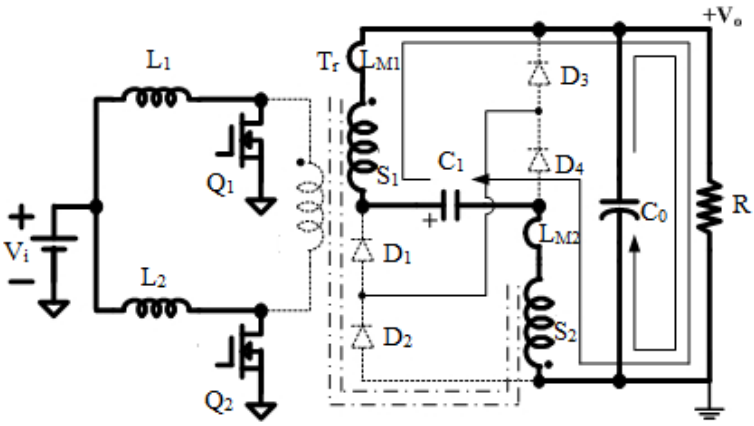



***Figure 3(c) MODE III [T2-T3]***

**D. MODE – IV [$T_3$-$T_0$] :-**

Fig 3(d) show the, we show that switch $Q_2$ is turned off at $T_3$. So , the inductor current $I_{L2}$is decreased & $I_{L1}$ is increased linearly. The input power is transferred to the load via transformer secondary winding $S_2$. The input power which is used to change the output capacitor $C_0$ through $S_2$-$L_{M2}$-$D_4$-$D_3$-$C_0$-$S_2$ and charge the clamped capacitor $C_1$ through $S_1$-$C_1$-$D_4$-$D_3$-$L_{M1}$-$S_1$ , respectively. In this mode the diode D3 & D4are turning on due to forward biased , so the voltage across D1 , D2 are clamped to VC1 & VC0 , respectively. The current maintain the following equation,

$$I_{S2} = I_{01} = \frac{I_o}{4} * \frac{2D-3}{D-1}$$

$$I_{S1} = I_{C1} = \frac{I_o}{4} * \frac{2D-1}{D-1}$$

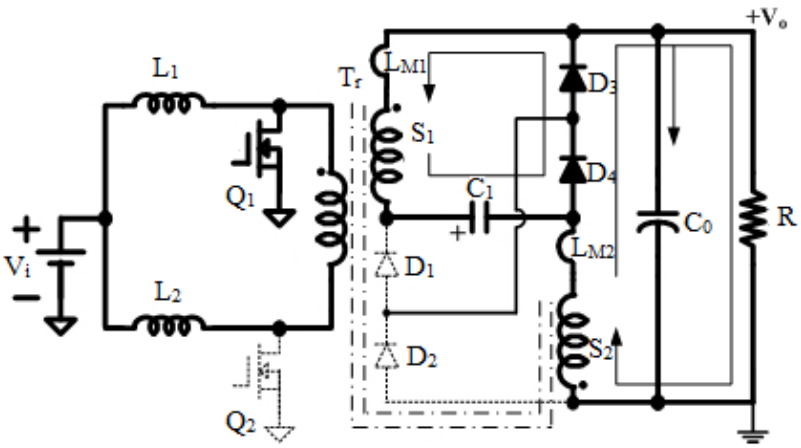



***Figure 3(d) MODE IV [T3-T0]***

At the time T0 the switch Q2 is turned again and the start the another switching cycle.

## III. MATLAB SIMULATION AND DESIGN CONSIDERATION

From Circuit Analysis there are two phases, Tcharge and Ttransfer within half of switching cycle .

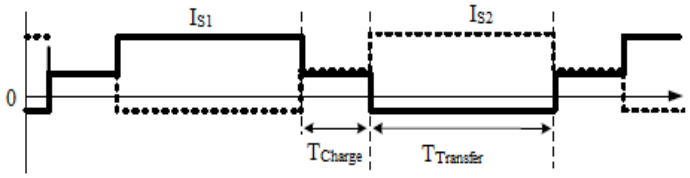



**Figure 4 Tcharge and Ttransfer phases**

The Tcharge and Ttransfer time intervals are given as follows

$$\text{Tcharge} = \left[D - \frac{1}{2}\right] * \text{Ts}$$

$$\text{Ttransfer} = [1 - D] * \text{Ts}$$

From the volt-second balance the relationship between output & input voltage can be derived as follow ,[4]

$$\frac{V_0}{V_{in}} = \frac{N}{[1-D]}$$

Where Duty cycle of each switch must be greater than 50% and converter is operated in continuous conduction mode. The turn ratio of transformer can be calculated as

$$N = \frac{[1 - D_{max}]}{V_{in.min}} * V_0$$

### 3.1 MATLAB SIMULATION OF TWO INDUCTOR BOOST CONVERTER :-

The parameter use for two inductor boost converter in open loop matlab simulation as follow ,

1 Input voltage [Vin] = 34
2 Input Inductor[L1,L2] = 165.5uH
3 Turn Ratio [S1:S2:S2] = 10:26:26
4 Switching Frequency[Fs] = 150khz
4 Clamping Capacitor[C1] = 2.2uF
6 Output Capacitor[C0] = 85uF

### [A] OPEN LOOP SIMULATION :-

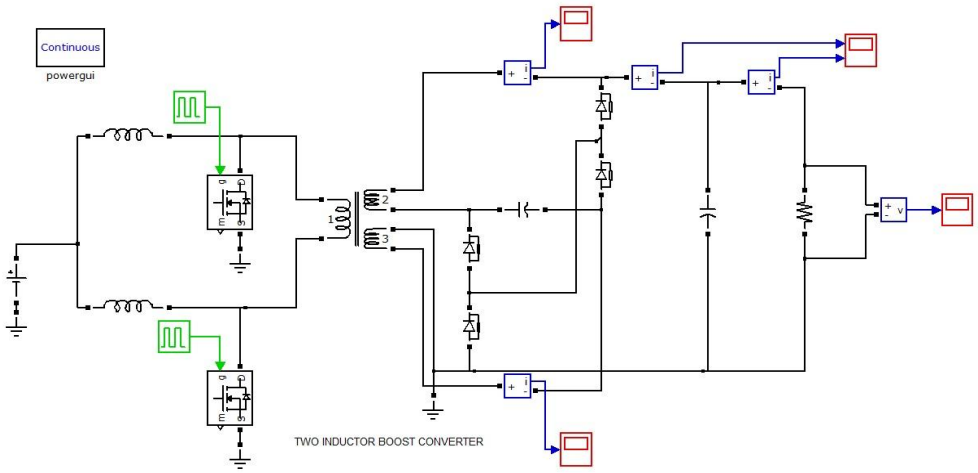



**Figure 5 Matlab Model Of Open Loop System**

**Simulation Results of open loop with resistive (linear) load :-**

Figure show the waveforms of Gate pulse , Secondary winding current , voltage across the diodes, output current ripple and output voltage ;

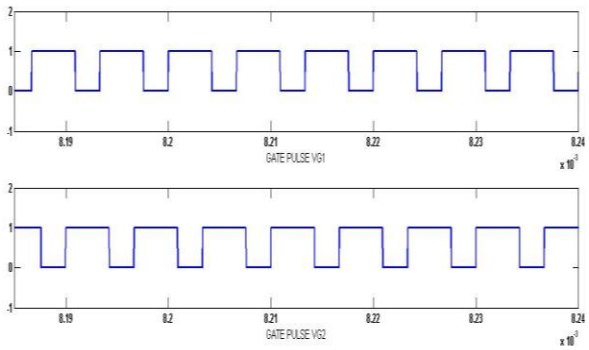



**Figure 6 Gate pulse of switch Q1 and Q2**

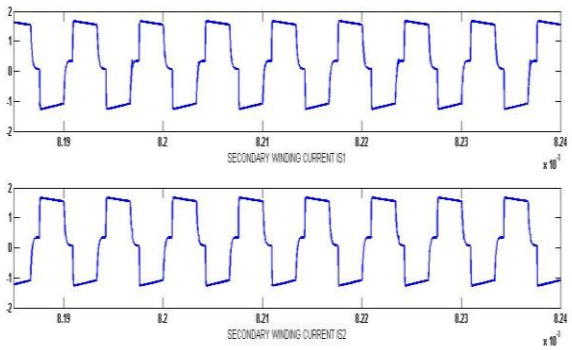



**Figure 7 Secondary winding Current [IS1] & [IS2]**

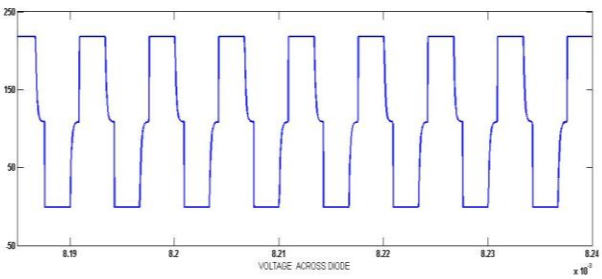



**Figure 8 Voltage across Diode [D1] [D2]**

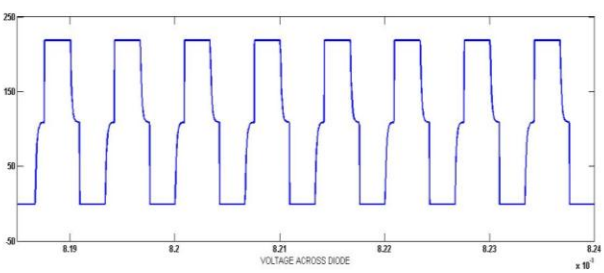



**Figure 9 Voltage across Diode [D3] [D4]**

Figure 6 show the secondary winding current $I_{S1}$ and $I_{S2,}$ In that the secondary current value is 1.7 A . Main Aim is to reduce the output ripple current , which is achieved using open loop matlab simulation ,There is no voltage stress across diode, which is shown in figure 8 & 9 . Figure 8 is the voltage across the diode $D_1$ and figure 9. is the voltage across the diode $D_3$ From Figure the leakage inductance energy of this two inductor boost converter is absorbed by the clamping capacitor $C_1$ . Therefore , the Voltage Spike on the rectifier diode is eliminated. The above simulation is for high- line light- load operation , from simulation there is 0.58A output ripple when the input voltage is 34V. show figure 10 .

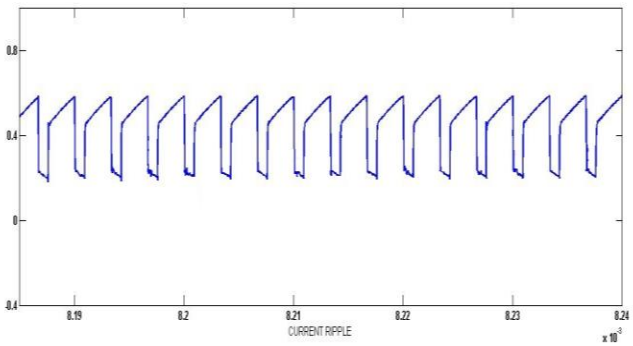



**Figure 10 Output Current Ripple**

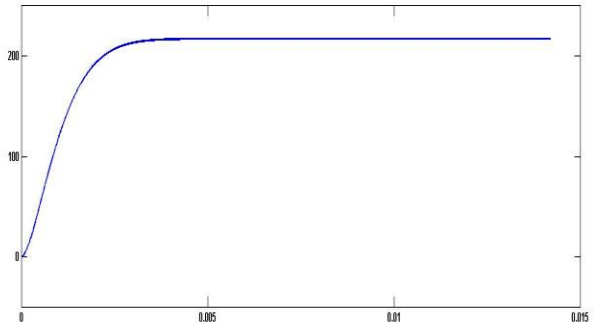


**Figure 11 Output Voltage**

With 34 V input voltage using the output voltage goes up to 200V .Show the Matlab Simulated Graph of output Voltage in figure 11.

**Simulation Result of open loop with non-linear load :-**

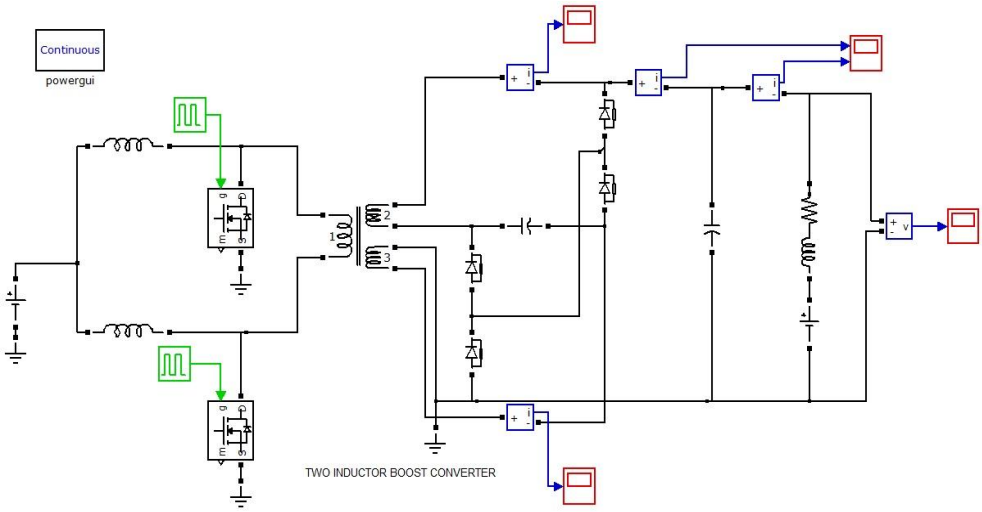



**Figure 12 Matlab Model with Nonlinear load**

With non-linear load the current ripple is also reduced using this two inductor boost converter topology , Figure 12 shows the current ripple of converter .

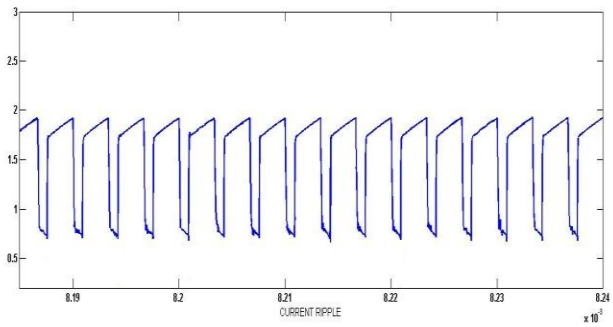



**Figure 13 Output current ripple**

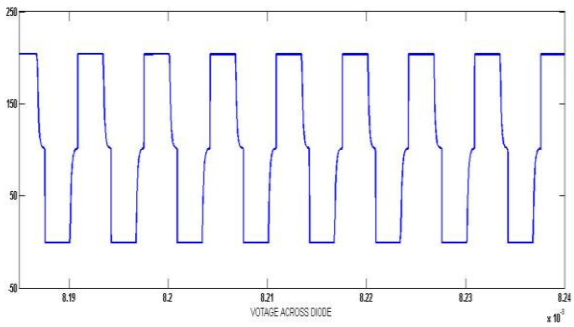
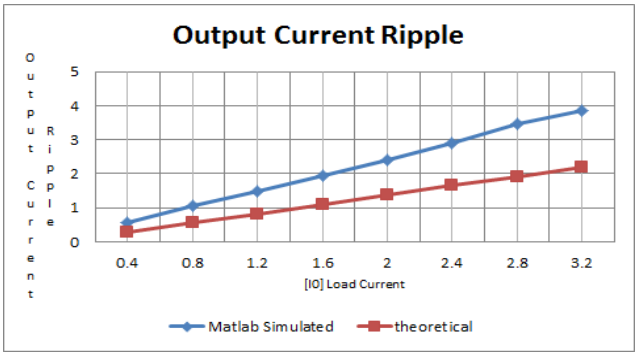



**Figure 14 Voltage across Diode**

**Comparison Of The Output Currents Ripples And R.M.S Currents Between The Simulated And Theoretical Results :-**

Figure 15 (a) and (b) , show the comparisons of the RMS current of the transformer secondary windings ($I_{S1}$ , $I_{S2}$) rms value and output current ripples ($I_{01}$) between the simulated results and theoretical results with different load conditions. Figure 15(a) show the matlab simulated value and theoretical value are closed but not completely matched. The load current incresed when the load across circuit is decreased, and according to that the output current ripples also incresed. Figure 15(b) shows the rms secondary winding ($I_{S1}$, $I_{S2}$) currents are close to the simulated results but not to matched . The reason is possible that the converter voltage gain equation ignore the forward voltage [$V_f$] of rectifier diodes and the voltage drop on the parasitic resistances.



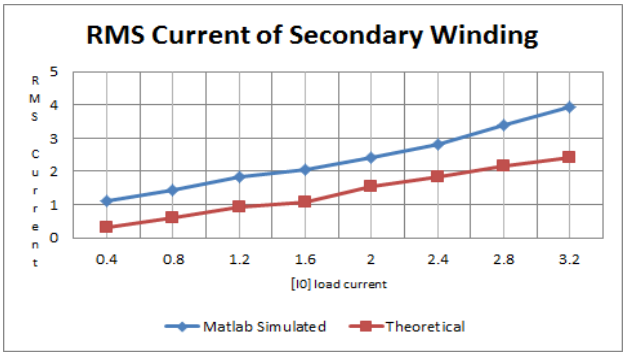




**Figure 15 (a) Comparison of the output current ripple** **Figure 15 (b) Comparison of the secondary current**

**[B] CLOSE LOOP SIMULATION :-**

The In the closed loop system is shown in Fig 16. The output voltage is sensed and it is compared with a reference voltage. Then error is processed through a PID controller. The output of PID controller adjusts the pulse width to maintain the output constant. Show the closed loop system of the two inductor boost converter in fig 16.

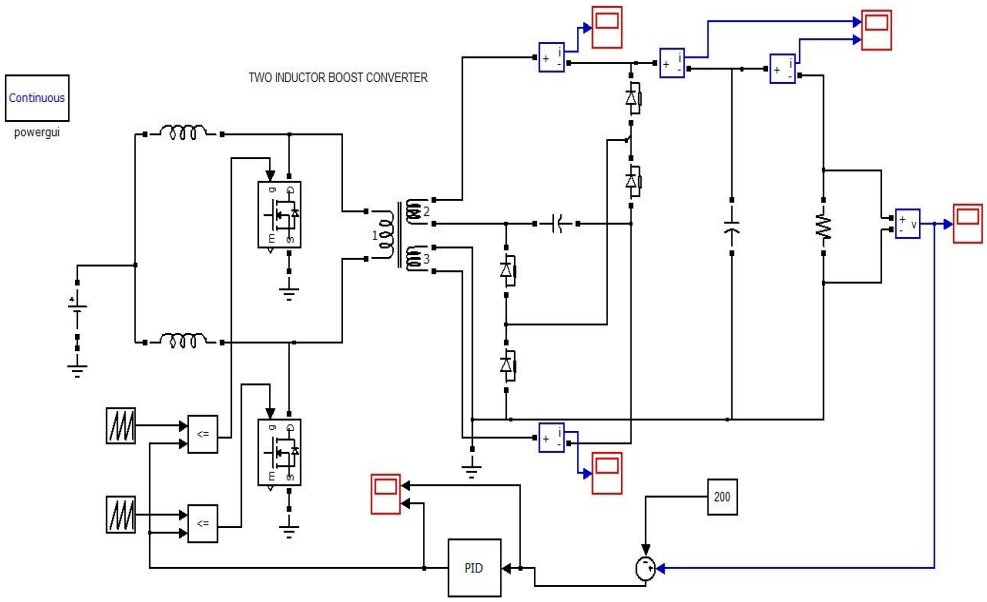



**Figure 16 Matlab Model Of Closed Loop System**

Figure 17 shows the secondary winding current $I_{S1}$ and $I_{S2}$ ,and figure 22 shows the output current ripple [$I_{01}$]. Figure 18 show the output current ripple in closed loop simulation .

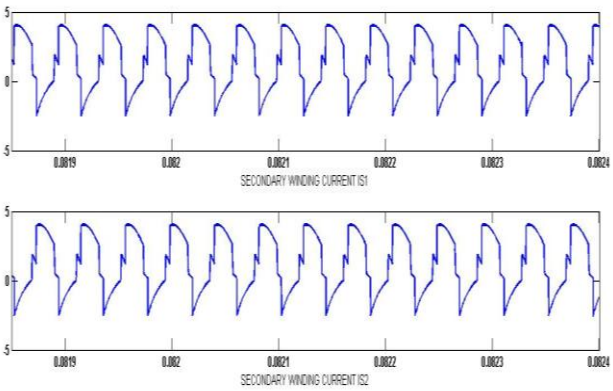



**Figure 17 Secondary Winding Current**

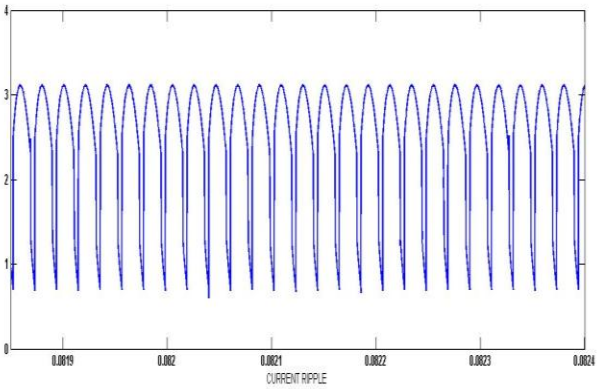



**Figure 18 Output Current ripple**

**[C] COMPARISON WITH OTHER TOPOLOGIES :-**

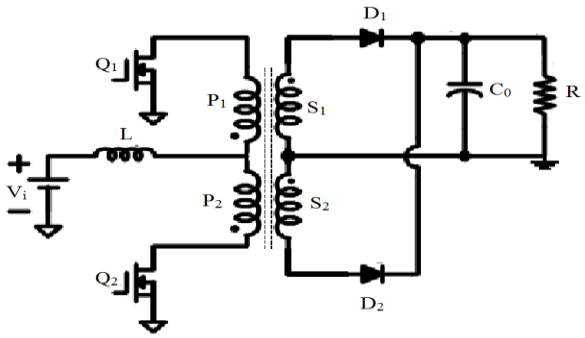



**Figure 19 (a) Current fed center trapped transformer**

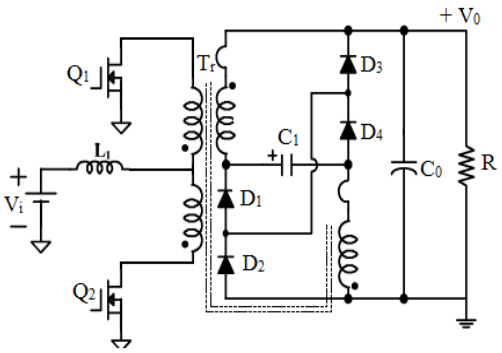



**Figure (b) Single Inductor Boost converter**

Comparison between the above two topologies with two inductor boost converter topology at $V_i$ =34 and $I_0$ =2 load condition is describe below ,

| parameters | Current fed Center-trapped transformer | Single inductor boost converter | Two inductor boost converter |
|---|---|---|---|
| Number Of Inductor | 1 | 1 | 2 |
| Voltage Stress Across Diode | 400 [$2V_0$] | 200 [$V_0$] | 200 [$V_0$] |
| RMS Current On Secondary Side | $I_{S1}$ =4.31<br>$I_{S2}$ =4.32 | $I_{S1}$ =4.00<br>$I_{S2}$ =4.00 | $I_{S1}$ =2.2<br>$I_{S2}$ =2.2 |
| Output Current Ripple | 3.2 | 3.1 | 0.7 |
| Primary Current | $I_{P1}$ =22.11<br>$I_{P2}$ =22.11 | $I_{P1}$ =15.88<br>$I_{P2}$ =15.88 | $I_{S1}$ =10.6 |

## IV. CONCLUSION

From the study the of this two inductor boost converter topology and reference paper on the basis of this topology the conclusion is made that using this topology the output current can be reduced . voltage spikes on rectifier diode can also be reduced , and efficiency can incresed. With help of clamping capacitor the output ripple current reduced , resulting minimize the number of output capacitor . Winding conduction losses are reduced due to the low RMS current on the secondary winding . Instead of one in that two inductor is used so the efficiency can be incresed because the input current is shared by two inductor and transformer circulation loss can be eliminated.
Ultimately this topology is good compare with other two inductor or analogy topologies .

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