CHAPTER 3

TWO INDUCTOR BOOST CONVERTER CIRCUIT

3.1 INTRODUCTION

This chapter deals with the analysis of two inductor boost converters. The boost converter serves the common purpose of having an output voltage higher than the input voltage. The boost converter has a single inductor and a single switch which is the basic configuration of the converter. The boost converters can be with multiple switches and multiple inductors. This chapter will analyze the performance of the TIB converter.

In high power off line power supplies, CCM boost rectifier is the preferred topology for implementing the front end converter with active input current shaping. All the proposed topologies use additional components to form an active snubber circuit that controls the turn off di/dt rate of the boost rectifier. The main features of the active approaches introduced the soft switching of the boost rectifier and the soft switching of the boost switch. In addition, the approaches described offer soft switching of the auxiliary switch together with the boost switch. The drawbacks of the boundary operating boost converter can be alleviated if two or more converters are interleaved.

Interleaving reduces the input ripple current and the peak input current and therefore an converter with the above said properties is considered in the present research work. The multiple switch and/or multiple inductor boost topologies are employed in high input current and/or high input to
output voltage conversion applications. Generally, interleaving is employed to reduce the input current ripple and therefore, to minimize the size of the input filter that would be relatively large if a single DCM boost converters were used. The operation of the interleaved boost converter at the CCM/DCM boundary under varying line and load current conditions requires variable switching frequency control which is often complex to implement than constant-frequency control.

The TIB considered in this work consists of a two inductor two switch boost converter topology that can achieve output voltage regulation from full load to no load in a wide input voltage range using constant frequency control. This topology employs an auxiliary transformer with a unity turns ratio to couple the current paths of the two boost inductors so that both inductors conduct identical currents. Due to this current mirror effect of the auxiliary transformer, no energy is stored in the inductors when there is no overlapping of conduction times of the two switches, i.e., when D=0. This auxiliary transformer approach can be applied to isolated or non isolated two inductor two switch topologies with any type of output rectifier.

The proposed interleaving circuit was evaluated and two CCM single phase, high power actor compared to rectifier implementations with respect to their efficiencies, compliance with the EN61000-3-2 specifications, complexity and costs.

3.2 TWO INDUCTOR BOOST CONVERTER

The circuit of a two inductor boost converter is shown in Figure 3.1. This two-inductor boost converter is chosen for its high input to output voltage conversion applications. The input side of the two inductor boost converter consists of two switches $S_1$ an $S_2$, two boost inductors $L_1$ and $L_2$, and Auxiliary Transformer (ATR). The output side of the circuit consists
of boost rectifiers \( D_1 \) and \( D_2 \) and output filter capacitors \( C_1 \) and \( C_2 \) connected across load \( R_L \).

![TIB converter circuit](image)

**Figure 3.1 TIB converter circuit**

The operation of the circuit can be explained through various time periods. During mode 1, the switch \( S_1 \) is closed. This makes the circuit complete, causing the flow of current. Therefore the current through the inductor \( L_2 \) forward biases the diode \( D_2 \) and the switch \( S_2 \) remains open, thereby the inductor discharges the energy stored in it.

During mode 2 both the switches \( S_1 \) and \( S_2 \) are turned ON. The current flow through the inductors \( L_1 \) and \( L_2 \) are increases at an equal rate. The capacitors \( C_1 \) and \( C_2 \) discharge their stored energy because the diodes \( D_1 \) and \( D_2 \) are reverse biased. As a result, the input part of the circuit is decoupled from the output part. During the mode 3, the switch \( S_1 \) is turned ON and the inductor which is charged in mode 2 discharges through capacitor \( C_1 \). During mode 4, the circuit repeats the operation as in mode 2.
3.3 ANALYSIS OF TWO INDUCTOR BOOST CONVERTER

The pulse and inductor current waveforms are presented in Figure 3.2. The current $i_{L1}$ in inductor $L_1$ increases during the entire on time of switch $S_1$. Similarly, current $i_{L2}$ in inductor $L_2$ increases during the on time of switch $S_2$ and decreases during its off time.

As a result, even when converter’s duty cycle $D$, which is defined as the ratio of the overlapping conduction time of the two switches and half of their switching period, is reduced to zero, the inductors continue to store energy since switches $S_1$ and $S_2$ are on for half of their switching period, is reduced to zero, the inductors continue to store energy since $T_s$. To reduce the store energy and extend the load regulation range, it is necessary to
shorten the conduction time of the switches. This can be accomplished by increasing the switching frequency.

\[ V_{IN} = v_1 + L_1 \frac{di_{L1}}{dt} \]  
(3.1)

\[ v_1 + L_1 \frac{di_{L1}}{dt} = -v_2 + L_2 \frac{di_{L2}}{dt} \]  
(3.2)

it follows that the same rate of change of \( i_{L1} \) and \( i_{L2} \), i.e., \( \frac{di_{L1}}{dt} = \frac{di_{L2}}{dt} \), can only be satisfied if

\[ v = \frac{L_2 - L_1}{L_2 + L_1} V_{IN} \]  
(3.3)

where \( v = v_1 = v_2 \) because \( n_{ATR} = 1 \). Therefore from Equations (3.1) through (3.3)

\[ \frac{di_{L1}}{dt} = \frac{di_{L2}}{dt} = \frac{V_{IN} - v}{L_1} \quad \frac{V_{IN} + v}{L_2} \]  
(3.4)

If both inductances have the same value \( L = L_1 = L_2 \), it follows that \( v=0 \) and

\[ \frac{di_{L1}}{dt} = \frac{di_{L2}}{dt} = \frac{V_{IN}}{L} \]  
(3.5)

The output is decoupled from the input when both switches are on and rectifiers \( D_1 \) and \( D_2 \) are reverse biased. As a result, during this stage the load current is supplied from the filter capacitors and capacitor voltages \( V_{CF1} \) and \( V_{CF2} \) slowly decrease, as seen in Figure 3.3. Since output voltage \( V_O = V_{CF1} + V_{CF2} \), the output voltage also slowly decreases.
Figure 3.3  Voltage waveforms across capacitor and output of two inductor boost converter

The voltage conversion ratio of the circuit can be calculated from the volt second balance on the boost inductors. From Figure 3.3, the volt-second balance equation for $L_1$ is

$$V_{IN}D\frac{T_S}{2} = \left(\frac{V_{CF}}{2} - V_{IN}\right)\left(\frac{T_S}{2} - D\frac{T_S}{2}\right)$$  \hspace{1cm} (3.6)

so that

$$\frac{V_o}{V_{IN}} = \frac{4}{1-D}$$  \hspace{1cm} (3.7)

Since $V_o = 2V_{CF}$. As can be seen from above equation the output voltage of the converter is at least four times larger than the input voltage. This high conversion ratio makes this converter very suitable for applications with a large difference between the output and input voltage.
3.4 OPEN LOOP AND CLOSED LOOP TWO INDUCTOR BOOST CONVERTER (RESISTIVE LOAD)

The TIB converter circuit is simulated using MATLAB/Simulink. The simulations are carried out for open loop and closed loop conditions for resistive load condition. The open loop controlled TIB boost converter is shown in Figure 3.4.

Figure 3.4 Open loop TIB converter simulation circuit
The circuit parameters adopted for the simulation circuit are presented in Table 3.1. The associated waveforms for the TIB converter are shown below. The disturbance subsystem is shown in Figure 3.5.

### 3.4.1 Open Loop Two Inductor Boost Converter (Resistive load)

In the ensuing section the simulation results of the TIB converter is presented. The simulation results presented are the input voltage waveform,
driving pulse waveform for the switches $S_1$ and $S_2$, the voltage waveform across switch $S_2$ and the output voltage waveform.

### 3.4.1.1 Results of Simulation

The open loop controlled two inductor boost converter is shown in Figure 3.4. The switches are two in number in order to increase the input to output voltage conversion and the current. The input voltage waveform is presented in Figure 3.6.

![Figure 3.6 Input voltage waveform for TIB converter](image1)

**Figure 3.6 Input voltage waveform for TIB converter**

![Figure 3.7 Driving pulse waveform of switch $S_1$ for TIB converter](image2)

**Figure 3.7 Driving pulse waveform of switch $S_1$ for TIB converter**
The TIB converter circuit is simulated using MATLAB/Simulink. The circuit is simulated for open loop conditions. The waveforms associated with the open loop circuit is measured and presented in this section.

**Figure 3.8 Driving pulse waveform of switch S₂ for TIB converter**

**Figure 3.9 Voltage waveform across switch S₁ for TIB converter**
Figure 3.10 Voltage waveform across switch $S_2$ for TIB converter

The driving pulse waveform for switch $S_1$ and $S_2$ is shown in Figure 3.7 and Figure 3.8. The voltage waveform across switches $S_1$ and $S_2$ is shown in Figure 3.9 and Figure 3.10.

Figure 3.11 Output voltage waveform of open loop TIB converter

The Figure 3.11 shows the output voltage waveform for open loop system of TIB converter. The operation of the TIB converter emphasizes the output voltage could not be controlled.
3.4.1.2 Experimental results of Open Loop Two Inductor Boost Converter

The hardware circuit is developed for the open loop operation of TIB converter. The top view of the hardware is shown in Figure 3.10.

![Figure 3.12 Power circuit](image)

**Figure 3.12 Power circuit**

![Figure 3.13 Inverter output voltage waveform of open loop TIB converter (Hardware)](image)

**Figure 3.13 Inverter output voltage waveform of open loop TIB converter (Hardware)**
Figure 3.14 Pulse waveform across switch $S_1$ for open loop TIB converter (Hardware)

Figure 3.15 Pulse waveform across switch $S_2$ for open loop TIB converter (Hardware)
The inverter output voltage waveform of the TIB converter circuit is shown in Figure 3.13. The pulse waveforms across switch $S_1$ and $S_2$ are presented in the Figure 3.14 and 3.15. The output voltage waveform is presented in Figure 3.16. The hardware results of the TIB for open loop condition closely agrees with the simulation results.

### 3.4.2 Closed Loop Two Inductor Boost Converter (Resistive load)

The closed loop controlled TIB converter is shown in Figure 3.17. The inverter output voltage waveform at the first stage of the converter is shown in Figure 3.18. The same set of simulation parameters as presented in the Table 3.1 are adopted for the closed loop operation of the TIB converter.
3.4.2.1 Results of Simulation

The simulation waveforms associated with the TIB circuit are presented in this section.

Figure 3.17 Closed loop TIB converter simulation circuit

Figure 3.18 Inverter output voltage waveform of closed loop TIB converter
The output voltage from stage I of the two inductor boost converter circuit is shown in Figure 3.18. The input to the circuit is DC and the stage I of the circuit converts it into AC. The waveform assumes significance here, because the AC is transferred from stage I of the circuit to stage II of the circuit without the help of a transformer, achieving better output voltage regulation. The output voltage of the two inductor circuit is shown in Figure 3.19.

The performance of the CAC boost converter is compared with the TIB converter. The comparative analysis will help us understand the suitability of the converter in lieu of their performance and the area where its application lies.

3.5 OPEN LOOP AND CLOSED LOOP TWO INDUCTOR BOOST CONVERTER (MOTOR LOAD)

The open loop controlled TIB converter fed PMDC motor is considered in this section. The converter is tested for its open loop and closed loop conditions and its torque and speed waveforms are measured.
3.5.1 Open Loop Two Inductor Boost Converter (Motor load)

The simulation results of the TIB converter for motor load are presented in this section. The motor is analyzed under torque disturbance conditions and its corresponding waveforms are presented. The open loop TIB converter is shown in Figure 3.20.

**Figure 3.20 Open loop TIB converter fed PMDC motor simulation circuit**

**Table 3.2 Simulation circuit parameters for two inductor boost converter (Motor load)**

<table>
<thead>
<tr>
<th>S. No</th>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Inductance $L_1$</td>
<td>3 mH</td>
</tr>
<tr>
<td>2.</td>
<td>Inductance $L_2$</td>
<td>3 mH</td>
</tr>
<tr>
<td>3.</td>
<td>Capacitance $C_1$</td>
<td>80 µH</td>
</tr>
<tr>
<td>4.</td>
<td>Capacitance $C_2$</td>
<td>80 µH</td>
</tr>
<tr>
<td>5.</td>
<td>Phase delay for switch $S_1$ (open loop)</td>
<td>0 sec</td>
</tr>
<tr>
<td>6.</td>
<td>Phase delay for switch $S_2$ (open loop)</td>
<td>25 µsec</td>
</tr>
</tbody>
</table>
Table 3.3 Simulation parameters for two inductor boost converter (Motor load)

<table>
<thead>
<tr>
<th>S. No</th>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Armature resistance $R_a$</td>
<td>0.05 $\Omega$</td>
</tr>
<tr>
<td>2.</td>
<td>Armature inductance $L_a$</td>
<td>0.01 H</td>
</tr>
<tr>
<td>3.</td>
<td>Field resistance $R_f$</td>
<td>240 $\Omega$</td>
</tr>
<tr>
<td>4.</td>
<td>Field inductance $L_f$</td>
<td>120 H</td>
</tr>
<tr>
<td>5.</td>
<td>Total inertia</td>
<td>0.05 kgm²</td>
</tr>
<tr>
<td>6.</td>
<td>Viscous friction coefficient $B_m$</td>
<td>0.02 Nm-s</td>
</tr>
</tbody>
</table>

The same set of simulation parameters are adopted for the closed loop operation of the TIB converter under motor load except the switching pulses as it would be generated depending upon the closed loop operation of the TIB converter circuit.

### 3.5.1.1 Results of Simulation

The simulation results for the open loop controlled TIB converter with motor load is discussed in this section.

![Speed waveform of open loop TIB converter fed PMDC motor](image)
The speed waveform is shown in Figure 3.21. The inference from the figure is that due to torque disturbance at 4 sec the speed also varies.

3.5.2 Closed Loop Two Inductor Boost Converter (Motor load)

The closed loop controlled two inductor boost converter fed DC motor system is shown in Figure 3.22. In the closed loop system, the output voltage is sensed and it is compared with a reference voltage.

The error is applied to a comparator through a PI controller. The output of PI controller is compared with a triangular wave to generate the driving pulse for driving S1. A similar process is applied for generating pulses to S2 by shifting the triangular wave. The output is controlled by the firing angles applied to the switches.

![Figure 3.22 Closed loop TIB converter fed PMDC motor simulation circuit](image_url)
3.5.2.1 Results of Simulation

The simulation results for the closed loop controlled TIB converter with motor load is discussed in this section. The speed waveform is shown in Figure 3.23.

![Speed waveform of closed loop TIB converter fed PMDC motor](image)

**Figure 3.23 Speed waveform of closed loop TIB converter fed PMDC motor**

From the Figure 3.23 it can be observed that the speed remains constant even when the motor undergoes torque disturbance. Thus the output voltage is maintained constant by using a closed loop system. From the simulation results, it is observed that the speed is constant when the converter operates in closed loop condition. Thus the closed loop system is able to maintain constant speed even though a torque disturbance is caused in the motor.

3.6 PERFORMANCE COMPARISON OF COMPOUND ACTIVE CLAMP BOOST CONVERTER AND TWO INDUCTOR BOOST CONVERTER

The two inductor boost converter and the compound active clamp converter are compared based on their input voltage, output voltage, input
power and output power. The results are tabulated and are presented in Table 3.4 and Table 3.5.

Table 3.4 Comparison of input voltage and output voltage

<table>
<thead>
<tr>
<th>S. No</th>
<th>Input voltage (V)</th>
<th>Output voltage (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>CAC</td>
</tr>
<tr>
<td>1.</td>
<td>46</td>
<td>164.3</td>
</tr>
<tr>
<td>2.</td>
<td>48</td>
<td>171.4</td>
</tr>
<tr>
<td>3.</td>
<td>50</td>
<td>178.6</td>
</tr>
<tr>
<td>4.</td>
<td>52</td>
<td>185.8</td>
</tr>
</tbody>
</table>

From the Table 3.4, it is inferred that the output voltage level of the two inductor boost converter is better compared to CAC boost converter. The graph is plotted in Figure 3.24.

Figure 3.24 Input voltage versus output voltage

From the Table 3.4, it is inferred that the output voltage level of the two inductor boost converter is better compared to CAC boost converter. The graph is plotted in Figure 3.24.
Table 3.5 Comparison of input voltage and output power

<table>
<thead>
<tr>
<th>S. No</th>
<th>Input Voltage (V)</th>
<th>Output power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>CAC</td>
</tr>
<tr>
<td>1.</td>
<td>46</td>
<td>449.8</td>
</tr>
<tr>
<td>2</td>
<td>48</td>
<td>489.9</td>
</tr>
<tr>
<td>3.</td>
<td>50</td>
<td>531.8</td>
</tr>
<tr>
<td>4.</td>
<td>52</td>
<td>575.4</td>
</tr>
</tbody>
</table>

Figure 3.25 Input voltage versus output power

The performance of the CAC boost converter and two inductor boost converter is predicted with input voltage ranging from 46 V to 52 V. The results obtained are summarized in Table 3.5. The results are plotted in Figure 3.25. The inference from the table is that the two inductor boost converter has higher output power compared to the CAC boost converter.

3.7 CONCLUSION

This chapter has discussed the performance of the TIB converter under both open loop and closed loop conditions. The TIB converter performance has been observed under open loop and closed loop conditions.
for resistive load. The converter has been fed with an input disturbance at the period of 0.3 sec under resistive load operation and the waveforms were measured. The performance of the TIB converter has been better under closed loop conditions even though disturbance was applied. This has been concluded from the waveform of the TIB converter under closed loop. This has been proved by better output load regulation in the closed loop compared to open loop. The closed loop TIB converter operating under resistive load consumes time of 0.02 sec for the voltage to get regulated. The closed loop TIB converter operating under motor load consumes time of 0.7 sec for the voltage to get regulated. The TIB converter performance was also observed under motor load conditions. The performance of the converter under closed loop condition proved to be better. This conclusion has been reached based upon the speed waveform of the TIB converter in closed loop operation.

The objective of observing the performance of TIB converter under open loop and closed loop conditions is being satisfied. The simulation results have proved that the closed loop operation of TIB converter has exhibited better performance.