CHAPTER 6

PERFORMANCE OF NBDC, NBDCCI AND IBDC WITH INVERTER

6.1 INTRODUCTION

Bidirectional converters are widely used in many applications such as automobile, satellite and telecommunication systems. The conventional converter increases the conduction loss and thus the current stress level is high on the device. In order to overcome this issue, the performance of a novel three different converters namely NBDC, NBDCCI and IBDC are analysed using various controllers in its feedback. In this chapter the performance of these converters are verified with RLE and BLDC motor load through an inverter. This chapter deals with the comparison of these three isolated and non-isolated DC-DC converters. The comparison is done in terms of mechanical power output, reduced torque ripple, THD and their corresponding results are presented.

6.2 PERFORMANCE ANALYSIS WITH RLE LOAD

The performance evaluation of three modules with RLE load is simulated using MATLAB simulation. The modules are analysed with an input DC voltage of 48V. The proposed modules are connected to RLE load through a three phase inverter topology. The harmonics present in the converter output is measured by Fast Fourier Transform (FFT) analysis.
6.2.1 NBDC with RLE Load

The proposed NBDC with quad filter and RLE load is shown in Figure 6.1. This implementation of quad filter helps in reduction of ripple content at the output. Thus the peak to peak voltage is low as compared to C-filter and Pi filter.

![Circuit diagram for proposed NBDC with RLE load](image)

**Figure 6.1 Circuit diagram for proposed NBDC with RLE load**

Figure 6.2 displays the converter output voltage in response to the input voltage about 48V. The DC link voltage of 96V shown in Figure 6.2 is converted to three phase AC using a three phase inverter. The inverter output is applied to RLE load. The waveforms of output voltage, output current and output power of the inverter are shown in Figure 6.2.

Since the bidirectional converter act as an interface in energy interaction, the harmonics plays a vital role and it should be reduced. FFT analysis is done and the frequency spectrum is shown in Figure 6.3. The output power of 148Watts is obtained.
Thus the THD of the proposed model with RLE load is measured about 14.10% which is shown in Figure 6.3.
6.2.2 NBDCCI with RLE Load

The MATLAB simulink model of proposed NBDCCI with RLE load is shown in Figure 6.4. The proposed converter is connected to RLE load through a three phase inverter. The DC link voltage of the converter of 131V is also shown in Figure 6.5.
Figure 6.5 shows the inverter output voltage, output current delivered to load and output power waveforms. The output power for the proposed converter is about 250 Watts.

![Waveforms and graphs](image)

**Figure 6.5 Simulation results for proposed NBDCCI with RLE load**

The performance of the power electronic converters is justified by its THD value. Thus Figure 6.6 shows the plot of harmonics order of about 6.30%.
6.2.3 IBDC with RLE Load

The proposed IBDC with quad filter and RLE load is shown in Figure 6.7. The DC link voltage of 97.35V shown in Figure 6.8 is converted into three phase AC using a three phase inverter.
The inverter output is connected to RLE load. Figure 6.8 illustrates output voltage, output current and the output power of the proposed converter.

![Graphs showing output voltage, output current, and output power](image)

**Figure 6.8 Simulation results for proposed IBDC with RLE load**

The output power of 150 Watts is obtained. From the results, it is inferred that the output voltage and current is free from ripple content. Figure 6.9 shows the THD of the proposed IBDC and is about 9.41%.
6.3 PERFORMANCE ANALYSIS WITH BLDCM LOAD

To study the benefits of the proposed converters in HEV applications, the proposed converters are operated with BLDCM Load. The performance evaluation of three converters fed PMBLDC drive systems is simulated using MATLAB simulation. The modules are analysed with an input DC voltage of 48V.

6.3.1 NBDC with BLDCM Load

Figure 6.10 shows the circuit diagram for proposed NBDC with BLDCM load. Figure 6.11 displays the DC link voltage and the inverter output voltage for the input DC voltage of 48V.
Figure 6.10 Circuit diagram for proposed NBDC with BLDCM load

Figure 6.11 Simulation results for proposed NBDC with BLDCM load
The commanded motor speed is shown which starts at zero and reaches the rated speed which is shown in Figure 6.12. The applied mechanical load torque to the BLDC motor is shown in the below waveform and it increases gradually from zero. An approximate measurement for mechanical output power is also shown in Figure 6.12.

![Waveform of Speed, Torque and Mechanical output power](image)

**Figure 6.12 Speed, Torque and Mechanical output power waveforms of proposed NBDC with BLDCM load**

The mechanical output power of 525.4Watts and load torque of 14.54Nm are obtained. The reduced torque ripple is 1.0Nm. The speed of the motor settles at 903.7rad/sec. FFT analysis is done and is shown in Figure 6.13. The THD of the proposed system with BLDCM is about 35.84%.
Figure 6.13 FFT analysis for proposed NBDC with BLDCM load

6.3.2 NBDCCI with BLDCM Load

The simulink model for proposed NBDCCI with BLDCM load is shown in Figure 6.14. The converter is connected to BLDC motor through quad filter and three phase inverter.

Figure 6.14 Circuit diagram for NBDCCI with BLDCM load
The DC link voltage of 131V is converted into three phase AC using a three phase inverter. The inverter output is applied to PMBLDC motor. Figure 6.15 displays the waveforms of inverter output voltage, speed, torque and power measurements of the system. The actual speed follows the commanded speed very closely and the desired speed is delivered by the system. The commanded torque is raised from zero gradually.

![Waveforms of inverter output voltage, speed, torque and power](image)

**Figure 6.15 Simulation results for NBDCCI with BLDCM load**
The mechanical output power of 586.3Watts and load torque of 15.21Nm are obtained. The torque ripple is reduced to 1.5Nm. The speed of the motor settles at 960rad/sec.

![FFT analysis](image)

**Figure 6.16 FFT analysis for proposed NBDCCI with BLDCM load**

Excessive harmonic currents injected into the power systems will disturb the grid stability. Therefore, it is necessary to reduce the harmonic contents produced by the switching elements in bidirectional converters. Thus the measured THD of the system is about 32.45% and is shown in Figure 6.16.

**6.3.3 IBDC with BLDCM Load**

The proposed IBDC with BLDCM load circuit diagram is shown in Figure 6.17. The inverter output voltage and speed of the motor waveforms are shown in Figure 6.18 for an input DC voltage of 48V. The Torque and mechanical output power waveforms are shown in Figure 6.19.
Figure 6.17 Circuit diagram for proposed IBDC with BLDCM load

Figure 6.18 Simulation results for proposed IBDC with BLDCM load
The output power of 439.3 Watts depicts the efficiency of the proposed system. The applied mechanical load torque to the BLDC motor increases gradually from zero and it value is 13.16 Nm. The torque ripple is reduced to 0.8 Nm. The speed of the motor settles at 834.6 rad/sec. From the Figure 6.20, it is inferred that the THD of the IBDC system is about 37.84%.

Figure 6.19 Torque and Mechanical output power waveforms of proposed IBDC with BLDCM load

Figure 6.20 FFT analysis for proposed IBDC with BLDCM load
6.4 RESULTS AND DISCUSSION

While designing the bidirectional converters, the trustworthiness and efficiency of the converter plays a vital role. Thus the output power, THD and reduced torque ripple evaluations are carried out for comparison analysis of three topologies with RLE and BLDCM load. Table 6.1 presents the comparison of proposed modules with RLE load and the same using BLDCM load is given in Table 6.2.

Table 6.1 Comparison of proposed converters using RLE load

<table>
<thead>
<tr>
<th>Type of proposed converter systems</th>
<th>Output power (Watts)</th>
<th>THD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NBDC</td>
<td>148</td>
<td>14.10</td>
</tr>
<tr>
<td>NBDCCI</td>
<td>250</td>
<td>6.3</td>
</tr>
<tr>
<td>IBDC</td>
<td>150</td>
<td>9.41</td>
</tr>
</tbody>
</table>

Table 6.2 Comparison of proposed converters using BLDCM load

<table>
<thead>
<tr>
<th>Type of proposed converter systems</th>
<th>Torque (Nm)</th>
<th>Rotor speed (rad/s)</th>
<th>Output power (Watts)</th>
<th>Reduction of torque ripple (Nm)</th>
<th>THD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NBDC</td>
<td>14.54</td>
<td>903.7</td>
<td>525.4</td>
<td>1</td>
<td>35.84</td>
</tr>
<tr>
<td>NBDCCI</td>
<td>15.21</td>
<td>960</td>
<td>586.3</td>
<td>1.5</td>
<td>32.45</td>
</tr>
<tr>
<td>IBDC</td>
<td>13.16</td>
<td>834.6</td>
<td>439.3</td>
<td>0.8</td>
<td>37.84</td>
</tr>
</tbody>
</table>
From table 6.1, it is found that NBDCCI using RLE load produces higher output power with low THD. From the table 6.2, it is observed that the torque ripple reduced is high in NBDCCI with BLDCM load and at the same time, THD is also low. This in turn increases the life time of the components present in the system. Figure 6.21 demonstrates the comparison of THD values of three proposed converters using RLE and BLDCM Load.

![THD Values Comparison](image)

**Figure 6.21 Comparison of THD values of proposed modules**

From the Figure 6.21, it is evident that the proposed NBDCCI using both RLE and BLDCM load produces high mechanical output power with low THD comparatively than other two proposed modules. From the results, it is inferred that for all conditions investigated, NBDCCI provides high output power, less harmonic distortion and reduced torque ripple. At the same time, the speed of the motor is high when it is driven using NBDCCI. This in turn increases the efficiency of the system for all types of loads. Hence, it is concluded that the proposed NBDCCI converter is more suitable for HEV applications when compared to other two proposed modules.
6.5 EXPERIMENTAL RESULTS

To verify the workability and effectiveness of the proposed NBDCCI, a prototype with RLE load shown in Figure 6.22 was carried out. This converter is tested for both forward and reverse mode of operation.

![Hardware implementation](image)

**Figure 6.22 Hardware implementation**

Figure 6.23 depicts the voltage waveforms of input and output respectively for the boost mode of operation. The gating signals for the BDC and inverter circuit and the inverter output voltage are also presented in Figure 6.23. If the converter is designed for operating in boost mode with ZVS, it can therefore operate with ZVS for the buck mode also.
From the above waveforms, it is noted that the ripple in the output voltage gets reduced by using quad filter. Therefore the proposed converter has the benefits of higher efficiency and high output power.

**6.6 SUMMARY**

The presented calculations and measurements affirm a comparable efficiency of the NBDC, NBDCCI and IBDC. Thus, the performance of these three modules is clearly demonstrated by both simulation and experiment. Among these, NBDCCI is identified as the most attractive converter because it enhances the performance of the system. Therefore, NBDC with coupled inductor converter system is a viable alternative to the existing systems.