CHAPTER 6

IMPLEMENTATION OF HYBRID MODULATION FOR HCMLI

6.1 INTRODUCTION

This chapter describes the design and construction of a 7-level HCMLI prototype to verify the proposed hybrid modulation scheme discussed in chapter-5. Bridge $H_1$ is constructed using Si IGBTs and bridge $H_2$ using SiC BJTs. Gating signals are generated using Xilinx Spartan-3A DSP processor. Hardware can be divided into the following sections: a Xilinx Spartan board, 7-level HCMLI setup and load configuration.

6.2 PULSE GENERATION

Xilinx Spartan 3-A DSP trainer is employed to generate the pulses required to trigger the Si IGBTs and SiC BJTs. The PWM pins AE3 to AF8 are used to generate the gating pulses of the respective devices. The PWM pulses are verified using MODELSIM as shown in Figure 6.1.
6.3 HCMLI Prototype

6.3.1 Bridge $H_1$

HCMLI consists of two bridges $H_1$ and $H_2$. Bridge $H_1$ is constructed using four Si IGBTs as shown in Figure 6.2. The construction of $H_1$ is divided into the following parts.

6.3.1.1 Optocoupler Isolation

Optocoupler shown in Figure 6.3 consists of LED and a phototransistor. When an electrical signal is applied to the input of the opto-isolator, its LED lights, its light sensor then activates, and a corresponding electrical signal is generated at the output. Unlike a transformer, the opto-isolators allow for DC coupling and generally provide significant protection from serious over voltage condition in one circuit affecting the other.
Figure 6.2 Photograph of the bridge $H_1$ of HCML1

![Bridge H1 with Si IGBT](image)

Figure 6.3 Pin details of optocoupler IC(4N35)

![4N35 Pin Details](image)

6.3.1.2 IGBT driver

IR2181 high speed IGBT gate driver chip as shown in Figure 6.4 is used to effectively drive the IGBTs by the control signals from FPGA.
IR2181 has the capability of independently driving two IGBTs (high side and low side) simultaneously with the high side operation voltage at upto 1200 volts.

![Typical connection of IR2181 driver](image)

Figure 6.4 Typical connection of IR2181 driver

### 6.3.1.3 IGBT power device

Power switches used for bridge H1 are FGA25N120 Si IGBTs, manufactured by International Rectifier. The fast recovery diode FR107 is used as feedback diode. The design of snubbers is important because at turnoff, stored energy in inductance generates surge voltage, which is applied to collector emitter of IGBT. The snubber capacitor is responsible for part of turn-off energy. Snubber circuit can suppress over voltage and incidental turn-off loss. The type of snubber used is RCD snubber as shown in Figure 6.5 where loss in Rs is reduced as the IGBT switches are operated at the fundamental frequency. As the value of Ic in IGBT is 10A, the value chosen for Rs is 100 Ω and Cs = 0.47uF.
Figure 6.5 Snubber circuit for Si IGBT

6.3.1.4 Switching pattern for bridge $H_1$

Figure 6.6 and 6.7 show the gating signals generated using FPGA for Si IGBTs which are switched at 50Hz.

Figure 6.6 Gating signals for switches $S_5$ and $S_7$ in bridge $H_1$
Figure 6.7 Gating signals for switches S₆ and S₈ in bridge H₁

The experimental output of bridge H₁ is shown in Figure 6.8.

Figure 6.8 Experimental output voltage for bridge H₁
6.3.2 Bridge H₂

Bridge H₂ is constructed using four SiC BJTs as shown in Figure 6.9. The construction of H₂ is divided into the following parts.

6.3.2.1 Optocoupler isolation

HCPL 4506 optocoupler modules are used for isolation between PWM logic output signal and the multilevel inverter circuit as shown in Figure 6.10. HCPL 4506 optocoupler consists of a GaAsP LED and a high gain photo detector to realize the isolation and to minimize propagation delay. These optocouplers improve the inverter efficiency through reduced switching dead time.

![Figure 6.9 Photograph of the bridge H₂ of HCMLI](image)

Figure 6.9 Photograph of the bridge H₂ of HCMLI
6.3.2.2 SiC BJT Driver

IXDD509 is used as a driver for SiC BJT. It consists of two 4-A CMOS high speed MOSFET gate drivers for driving the BJTs. Each of the output can source and sink 4 A of peak current while producing voltage rise and fall times of less than 15ns. The input of each driver is TTL or CMOS compatible and is virtually immune to latch up. This IC has the unique capability of driving the high power SiC BJTs by limiting the di/dt transients.

6.3.2.3 SiC BJT power device

ButSiC 1206, 1200V, 6A BJT is used as a power device for bridge H2. These transistors have unique properties like very low losses, capability to handle high voltages and operation at very high temperatures. The fast recovery diode FR107 is used as feedback diode.

6.3.2.4 Switching pattern for bridge H2

The gating pulses for SiC BJTs which are switched at 39.50 kHz is shown in Figures 6.11 and 6.12.
Figure 6.11 Gating signals for $S_1$ and $S_3$ in bridge $H_2$

Figure 6.12 Gating signals for $S_2$ and $S_4$ in bridge $H_2$

The experimental output voltage for bridge $H_2$ is shown in Figure 6.13.
Figure 6.13 Experimental output voltage for bridge $H_2$

The output voltages of bridge $H_1$ and $H_2$ are added and the cascaded output for resistive load is shown in Figure 6.14.

Figure 6.14 Seven-level output voltage of HCMLI
For RL (R = 30 \, \Omega, \, L = 24\, mH) load, the experimental output are shown in Figures 6.15 and 6.16.

**Figure 6.15** Experimental output for HCMLI (RL Load)

**Figure 6.16** FFT spectrum for load current and voltage of HCMLI (RL load)
The switching transients along with turn-on and turn-off loss evaluation for Si IGBT and SiC BJT are shown in Figures 6.17 and 6.18.

Figure 6.17 Switching transients for SiC BJT

Figure 6.18 Switching transients for Si IGBT
Table 6.1 Comparison of simulation and experimental results for switching loss and THD

<table>
<thead>
<tr>
<th>Type of load</th>
<th>Switching losses (mJ)</th>
<th>THD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Simulation results</td>
<td>Experimental results</td>
</tr>
<tr>
<td>HCMLI (Si IGBT and SiC BJT) for RL load</td>
<td>4.64</td>
<td>4.855</td>
</tr>
</tbody>
</table>

Table 6.1 shows the experimental results for switching loss and THD which are close to that of simulation results for HCMLI using the proposed hybrid modulation PWM technique.

6.4 CONCLUSION

The experimental output voltage and current waveforms of HCMLI are obtained using the proposed modulation technique. Switching loss and FFT spectrum of load voltage and load current for HCMLI has been observed. It is found that the proposed PWM technique is simple and it promises permissible harmonic distortion of output voltage and reduced switching losses. The application of SiC BJT which is switched at higher frequency for HCMLI improves its performance. Therefore, the proposed HCMLI is a suitable choice for fuel cell based power generation.