INTRODUCTION

- The excellent material properties of silicon carbide (SiC) semiconductors offer great promise for increasing the DC link voltage to well over 1 kV, while maintaining high efficiency and also achieving smaller more cost effective power conversion through faster switching.

- The ability to increase the DC-link voltage up to 4 kV per switch level, is an application especially attractive for SiC unipolar devices, for example, a JFET or MOSFET rated at 6.5 kV, could easily accommodate such operational voltages, while maintaining high switching speeds of 20 kHz.

- Unipolar SiC JFETs can enable small, lightweight, transformerless topologies for industrial medium voltage grid applications operating in the 3.3 kVAC or 4.16 kVAC regimes.

6.5 kV SiC JFET PERFORMANCE

- SiC JFETs have demonstrated robust reliability over that of SiC-MOS technologies.
- SiC JFETs have the added advantage of reliable operation at $T_{amb} > 300^\circ$C, limited only by packaging.

Fig. 1 USCi’s Enhanced mode 6.5 kV SiC JFET forward conduction (a), and drain leakage showing ~7 kV blocking (b).

- DC-link Voltage
- Input Voltage
- Max Input Power
- Conversion
- DC-Link
- Transformer
- Voltage
- Transformer
- Voltage
- Transformer

6.5 kV SiC DIODE PERFORMANCE

- SiC Diodes offer near zero Qrr, (reverse recovery losses) and demonstrate excellent high current operation.

Fig. 3 USCi’s 6.5 kV SiC JBS Diode forward conduction (a), and cathode leakage showing >7 kV blocking (b).

6.5 kV SiC JFET POWER HALF-BRIDGE MODULE

- The normally-off 6.5 kV JFETs will be assembled with the 6.5 kV Diodes in antiparallel to form a 20 kHz half-bridge power module rated with the following parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drain Voltage</td>
<td>$V_D$</td>
<td>6500</td>
<td>V</td>
</tr>
<tr>
<td>Gate-Source Voltage</td>
<td>$V_{GS}$</td>
<td>$-20$</td>
<td>V</td>
</tr>
<tr>
<td>Continuous Drain Current</td>
<td>$I_{DSS}$</td>
<td>60</td>
<td>A</td>
</tr>
<tr>
<td>Pulse Drain-Sink</td>
<td>$T_{PD}$</td>
<td>100</td>
<td>A</td>
</tr>
<tr>
<td>Max Operating Temperature</td>
<td>$T_{jmax}$</td>
<td>125</td>
<td>°C</td>
</tr>
<tr>
<td>Voltage</td>
<td>$V_J$</td>
<td>$30$</td>
<td>kV</td>
</tr>
<tr>
<td>Drain-Source On-Resistance</td>
<td>$R_{DS(on)}$</td>
<td>$150$</td>
<td>mΩ</td>
</tr>
</tbody>
</table>

Fig. 5 Schematic of half-bridge power module (a) and final module design (b).

6.5 kV JFET MODULE APPLICATION

- CASE STUDY: Simulation of Neutral Point Clamped (NPC) inverter for transformerless grid-tie to 4.16 kVAC using SiC-JFET half-bridge module.

Fig. 6 Three-level neutral point clamped inverter enabling a 8 kV DC link for direct tie into an industrial distribution line at 4.16 kV AC.

- 4 kV DC per switch
- 8 kV DC
- 4.16 kV AC

6.5 kV JFET POWER FULL-BRIDGE MODULE

- Fig. 7 Efficiency simulation of JFET modules and NPC inverter up to 250kVA output (a) and power density and cost benefit estimations on 250kVA inverter (b).

<table>
<thead>
<tr>
<th>Device Type</th>
<th>Efficiency (%)</th>
<th>Power Density, (W/mm²)</th>
<th>S/C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical 6.5 kV SiJFET</td>
<td>90</td>
<td>60</td>
<td>0.2</td>
</tr>
<tr>
<td>NPC 6.5 kV SiJFET</td>
<td>95</td>
<td>3.75</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Summary

- 6.5 kV SiC JFET and JBS Diode devices were fabricated for assembly and testing in half-bridge modules rated at 60 A, 20 kHz, and $T_{amb} = 200^\circ$C operation.
- Higher DC-link voltage capabilities enable next generation transformerless topologies.
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