All-SiC Power Module for Grid-tied Energy Storage

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Acknowledgement: The authors thank Dr. Imre Gyuk for funding this work and Dr. Stan Atcitty for technical contributions. Sandia National Laboratories is a multi-mission laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SBIR Phase I Grant DE-SC0013816 SAND2016-9237 C
Battery Energy Storage Power Electronics Architectures

- Bidirectional, isolated DC-AC Power Conversion systems needed
- High Efficiencies are needed due to two-way power flow
- Compact systems help in wider deployments
- Low Frequency Transformer occupies space
Multi-level Converters using High Frequency commodity SiC Transistors

- Bidirectional 800 V grid-scale battery connections on secondary side
- 1700 V and 1200 V SiC devices required for high frequency secondary side connection
Compact, High Efficient Architecture enabled by High Voltage Devices

- SiC affords 1-3% increase in conversion efficiencies
- Higher Operating frequencies (5-10 kHz) results in compact systems
- Commodity, 1700 V SiC Transistors can be put in series to achieve low cost for 4160 V AC and 12.47 A AC systems
Results in Phase I of study

- At 1200 V bus voltages, SiC Transistors offer lower switching as well as conduction losses as compared to the fastest state-of-the-art Si IGBTs.
Series Connected Device Architecture

Diagram showing series connected devices with symbols for voltage $V_{dc}$ and $V_A$, and current $I_{total}$.

Graphs showing waveforms for $I_L (50A/Div)$, $V_{ds1} (200V/Div)$, $V_{ds2} (200V/Div)$, $V_{gs2} (5V/Div)$, and $I_{total} (100A/Div)$.

Additional notes on waveform parameters.
Series Connection of SJTs proven with simulations and measurements
Calculated Loss Comparisons at 1 MVA

Table 1: Medium Voltage/Low Current Side loss even at 1 MVA operation.

<table>
<thead>
<tr>
<th>Active Power (MW)</th>
<th>Reactive Power (MVAR)</th>
<th>Loss (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>3064</td>
</tr>
<tr>
<td>0.8</td>
<td>0.6</td>
<td>4175</td>
</tr>
<tr>
<td>0.6</td>
<td>0.8</td>
<td>5330</td>
</tr>
</tbody>
</table>

Table 2: Low Voltage/High Current Side Loss

<table>
<thead>
<tr>
<th>Active Power (MW)</th>
<th>Reactive Power (MVAR)</th>
<th>Loss (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>32</td>
</tr>
<tr>
<td>0.8</td>
<td>0.6</td>
<td>27</td>
</tr>
<tr>
<td>0.6</td>
<td>0.8</td>
<td>23</td>
</tr>
</tbody>
</table>
High-frequency (10 kHz) transformer configuration for the DC-DC DAB stage. The four limbs of the three transformers are connected in star and delta fashion to produce a stepped waveform at the middle limb of the transformer.
Status and Future Efforts

- **Current Status**
  - Phase I Project July 2015 – March 2016
  - Phase II Project started Aug 1, 2016
  - Modeling of Circuit Losses completed
  - Series connected devices being scaled up to higher power

- **Future Efforts in Phase I**
  - Complete SPICE Modeling of Devices to be used for 4160 V AC, and then 12.47 kV AC
  - Quantify the impact of All-SiC based power electronics on grid-tied energy storage systems
  - Work with commercialization partners by making a 400 kW demonstration at
Grant Details

- Principal Investigator: Dr. Ranbir Singh and Prof. Subhashish Bhattacharya
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