Energy Efficiency Through Innovation

All-SiC Power Modules for Energy Storage Power Electronics

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Energy Storage Opportunities at Medium Voltages (3-20 kV)

- Many Energy storage opportunities require power electronics that can enable conversion efficiencies needed for making energy storage viable
- Silicon Carbide high voltage devices will play a pivotal role
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

Diagram:

- Isolated DC-DC converter
- PWM DC-AC inverter
- Low freq. transformer
- 800 Vdc Nom.
- 480 V AC rms
- 15 kV class
- CEC η=95%
- CEC η=99%
- 800 Vdc Nom.
- Multilevel DC-AC inverter
- 15 kV class
- CEC η=98%
### Calculated Loss Comparisons at 1 MVA

**Table 1: Medium Voltage/Low Current Side**

<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>

Loss even at 1 MVA operation.

**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>
Why SiC Power Devices?

**Intrinsic properties**
- 3X Thermal conductivity of Si
- 3X High bandgap of Si ➔ 10X high breakdown field

**Device performance**
- High current density
- Fast switching
- Low Rdson

**System benefits**
- High temperature operation
- System size and weight reduction
- Reduction of conduction and switching loss
GeneSiC’s Power Discrete and Module Roadmap

SiC MOSFETs and Rectifiers

- **3300 V**
  - 1 A
  - 5 A

- **1700 V**
  - 20 A
  - 50 A
  - 100 A
  - 400 A

- **1200 V**
  - 1 A
  - 5 A

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Ultra High Voltage devices

SiC MOSFETs, Thyristors and Rectifiers

- >15 kV
- 10 kV
- 6.5 kV

50 A  200 A  1000 A  4000 A
• SiC Planar DMOSFETs fabricated on 35 µm thick, \( \approx 2.8 \times 10^{15} \text{ cm}^{-3} \) doped N- drift epilayers

• The device design space constituted different JFET Doping Profiles, Channel Lengths and JFET spacings
Output and Blocking Characteristics

- 2.74 mm x 2.74 mm die
  - Active Area = 0.046 cm²
- $R_{on,sp}$ of 17.0 mΩ-cm², and breakdown voltage of 4600 V measured at 25°C
- BV close to theoretical limit for 35 µm/3x10^{15} cm⁻³ thick N-drift layer
- $V_{TH}$ extracted as 2.4 V (at $I_D = 5$ mA)
Breakdown voltage increases linearly with measurement temperature.

Extracted temperature co-efficient of avalanche breakdown as 1.33 V/°C.
50kW Test Bench

Triple Active Bridge:

► Integration of photovoltaic and energy storage

Triple Active Bridge Setup at FREEDM System Center (50 kW)
Double Pulse Switching Characterization

- $V_{DS}$ fall time = 30 ns achieved for switching at 1800 V and 6 A, with +20 V drive voltage and $R_{G,ext} = 10 \, \Omega$
Double Pulse Switching Characterization

- $V_{DS}$ rise time = 30 ns achieved for switching at 1800 V and 6 A, with -3.3 V Gate Drive Voltage
Half Bridge Operation of 3300 V Devices

Half bridge Operation:

► Inductor is connected and the device are switched at different values of current to test the operation of the devices

► Switching Frequency from 5 kHz to 10 kHz is applied

![Graph showing voltage and current measurements for a half bridge circuit with 3300 V devices.](image-url)
Status and Future Efforts

• **Current Status**
  – Technology developed for commercially viable 3300 V SiC MOSFETs
  – Up to 4600 V SiC MOSFETs demonstrated
  – Phase I Project July 2015 – March 2016
  – Phase II Project started Aug 1, 2016

• **Future Efforts in Phase I**
  – Scale up the voltage ratings to 6500 V
  – Scale up Current ratings to 50 A
  – 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
Grant Details

- Principal Investigator: Dr. Ranbir Singh
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Multi-level Converters using HF/SiC Transistors at >3300 V

- Bidirectional 800 V grid-scale battery connections on secondary side
- 3300 V and 6500 V SiC devices required for high frequency secondary side connection
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Double Pulse Switching Characterization

- Energy Losses are extracted from switching waveforms measured at various drain current levels and different gate drive voltages.
- 22% decrease in $E_{ON}$ observed, when gate drive voltage is increased from +15 V to +18 V.
- Further increase of drive voltage from +18 V to +20 V only yielded 9% improvement in $E_{ON}$.