SiC MOSFETs for Future Resonant Converter Applications

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**HiPPE – High Performance Power Electronics with Wide Bandgap Power Semiconductors for Industrial, Marine, Renewable Energy and Smart Grid Applications**

<table>
<thead>
<tr>
<th>Partners</th>
<th>Resources</th>
</tr>
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<tbody>
<tr>
<td>• NTNU</td>
<td>• 10 MNOK</td>
</tr>
<tr>
<td>• Siemens</td>
<td>(RCN 8, partners 2)</td>
</tr>
<tr>
<td>• Eltek</td>
<td>• 2 PhD students</td>
</tr>
<tr>
<td>• EFD Induction</td>
<td>• WP on EMC and Compact Design</td>
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<td>• Vacon</td>
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<td>• Norwegian Electric Systems</td>
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<td>• Statkraft</td>
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<td>• SINTEF Energy</td>
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Paradigm shift in power electronics due to new “wide bandgap” semiconductors, GaN and SiC
SiC MOSFET

HIGH VOLTAGE
HIGH CURRENT

HIGH FREQUENCY
Introduction and motivation for this paper

- The arrival of SiC has opened new opportunities enabling the development of high voltage devices even in unipolar structure.

- Before using these devices in a commercial application, it is crucial to understand their performance gain compared to their Si counterparts.

- Therefore, in this paper, the calorimetric loss evaluation is performed in a full-bridge series resonant converter using 1.2 kV SiC MOSFET module and a 1.2 kV Si IGBT module.
Devices under test (DUT)

- Both the selected half-bridge modules are commercially available in a standard plastic package, and have similar power ratings.
- On-state resistance and offset voltage at 2 different temperatures are listed in the table.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>CAS300M12BM2 SiC MOSFET</th>
<th>SKM400GB125D Si IGBT</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{dson}/R_{ceon}$ (mΩ)</td>
<td>5</td>
<td>6.3</td>
</tr>
<tr>
<td>$V_{CEO}$ (V)</td>
<td>Absent</td>
<td>1.4</td>
</tr>
</tbody>
</table>

25 (°C) 125 (°C) 25 (°C) 125 (°C)

5 7.8 6.3 7.6

Absent Absent 1.4 1.7

Internal layout of CAS300M12BM2 (Cree).

Photograph of SiC MOSFET

Package: 62mm x 106mm x 30mm
Measured turn-off of SiC MOSFET vs Si IGBT

- Tail current in an IGBT during turn-off causes more loss, which is strongly dependent on junction temperature.
- $V_{ds}/V_{ce} = 500\, \text{V, } I_{ds}/I_{ce} = 120\, \text{A, } T_j = 25\, ^\circ\text{C} - 125\, ^\circ\text{C}$ (step of 25 °C)

Turn-off of SiC MOSFET.

Turn-off of Si IGBT.
Datasheet output characteristics of SiC MOSFET vs Si IGBT

- On-state loss
  - in SiC MOSFET has only the resistive part, while that in Si IGBT has an offset voltage in addition.
  - in both devices resistance increases with increase in junction temperatures.
Schematic diagram of the experimental setup for induction heating application

• Input power of the converter is measured in the dc-link ($V_{dc}$ is measured by a precision voltmeter and $I_{dc}$ by LEM current sensor) and the loss is measured using calorimetric method. $Q = m \cdot s \cdot (T_{out} - T_{in})$
Laboratory results

- Input power of the converter is 84 kW and the switching frequency is 190 kHz.

<table>
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<tr>
<th>DUT</th>
<th>$P_{sw}$ (W)</th>
<th>$P_{con}$ (W)</th>
<th>$P_{sw}/P_{cond}$</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiC MOSFET</td>
<td>348</td>
<td>272</td>
<td>1.28</td>
<td>99.2</td>
</tr>
<tr>
<td>Si IGBT</td>
<td>4480</td>
<td>1440</td>
<td>3.11</td>
<td>92.9</td>
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</table>
Conclusions

• With SiC MOSFET solution, the inverter efficiency is 99 %, whereas that with Si IGBT solution is 93 %; a gain of 6 % points at a switching frequency of about 200 kHz.

• This gain in efficiency can be utilized for, in this application:
  - Reducing the cooling requirement, which eventually reduces the converter footprint.
  - Or by increasing the switching frequency, the benefit of Skin effect can be utilized for surface heating of relatively small parts or tubes with small diameters where only a thin layer of the surface should be hardened or welded.

• More generally, SiC devices make converters more efficient, more compact, and gives higher bandwidth for the control system.