Solid-State Power Substation (SSPS) - Background

- Part of DARPA ‘High Power Electronics (HPE)’ program
- Objective – compact, light-weight power converters & transformers for US Navy enabled through high voltage SiC switches

Low Frequency Conventional Transformer (analog)
- 2.7 MVA
- 13.8kV/450V (Δ/Y) 60Hz
- 6 tons/each
- 10 m³/each
- fixed, single output

Estimated SiC-based Solid State Power Substation (digital)
- 2.7 MVA
- 13.8kV/465V (Δ/Y) 20 kHz
- 1.7 tons/each
- 2.7 m³/each
- multiple taps/outputs

Demonstrator Transformer:
13.8kV AC – 465V AC High Frequency Solid State Power Substation (SSPS)
Solid-State Power Substation (SSPS) - DARPA ‘High Power Electronics (HPE)’ Program

- GE Global Research: System Design/Integration, Component Characterization
- Cree: SiC Devices/Packaging
- Powerex: High frequency Transformers
- General Dynamics Electric Boat: Ship Integration Requirements
- University of Wisconsin Madison: Modeling, Alternative architectures
High frequency transformers size reduction

220 kVA, 60 Hz dry-type xfmr

330 kVA, 60 Hz oil-filled xfmr (1,220 kgs)

Oil-filled design, water-cooled (45 kgs, IAP Research)
Dry-type design, forced air-cooled (35 kgs, Los Alamos)

250 kVA, 20 kHz transformers
SiC switches - size and performance benefits

SiC module, 10 kV, 120 amps (Cree, Powerex)
- Conduction drop < 6 V
- Switching time < 100 ns

Si IGBT assembly, 10kV, 160 amps
(3x 4.5 kV devices in series)
- Conduction drop > 10 V
- Switching time > 3 ms

SiC Module: turn-on/turn-off @ 5kV, 100A
SSPS - Prototype 250 kVA Building Block

- High frequency transformer
- 10 kV SiC bridge
- 13.8 kVAC_{LL}
- 267 VAC_{LN}

Building block

10 kV SiC bridge

HF transformer
SSPS 1 MVA Prototype Test Results

Single-phase SSPS at Navy test lab

✓ Demonstrated at 1 MVA, 13.8 kV/265 V
✓ Efficiency at full load > 97%
✓ 1/3rd weight of conventional transformer
✓ Clean 20 kHz waveforms
✓ Balanced sharing of voltages/ currents
✓ AC input current/ output voltage THD < 5%
Thermal Measurements

SSPS temperature measurements – 2 hour load test

- Inlet water – 25C
- SiC Modules – low temp rise
- Cooling of HF transformers and busbar/ connections is challenging
HPE program - Ongoing Development

• Option Program
  - 1 MW, 4160Vac – 1000Vdc supply for AMDR radar,
  - TRL6 testing in Q4 2012

• 1/3\textsuperscript{rd} volume, 1/10\textsuperscript{th} weight of existing supply

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<thead>
<tr>
<th>Present PCM-4</th>
<th>SiC PCM-4/1A</th>
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<tr>
<td>Weight: 35,000 lbs</td>
<td>3,500 lbs</td>
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<tr>
<td>Volume: 168”W x 60”D x 81”H</td>
<td>60”W x 60”D x 60”H</td>
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Prototype under assembly
Testing July 2012 – Real-Time Digital Simulation
Power Hardware and Control hardware in the Loop Testing
Potential Industry Applications

Renewables
- Enable power conversion and grid interface at higher voltage to reduce complexity and cost

Rail
- More efficient locomotive drives - reduce switching/diode recovery losses
- Compact transformers/electronics for catenary interface

T&D
- Reduce number of series devices needed to handle high voltage.
- HVDC/ FACTS converters with lower component count/ complexity
- Compact solid-state distribution transformers
  (smaller footprint, added functionality, oil-free)
Challenges for high voltage SiC

• Cost – need market volume and higher yields
• Reliability - need validation from early adopters
• Limited current ratings for present devices/ modules
  - T&D, Drives, Wind applications will require higher ratings
  - Need large-area chips with good yields
• Development of supporting HV components – passives, gate drives, packaging, insulation, ..
• For HV applications, need to be cost-competitive compared with multilevel converters with LV silicon