A Power Dense Advanced Power Inverter (API) for Grid Tied Energy Supplies

Phase I & Phase II SBIR: DOE Energy Storage Program, Dr. Imre Gyuk, and Technical POC Dr. Stan Atcitty, Sandia National Laboratories

Creare LLC
Bruce R. Pilvelait
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Creare: Commercializing New Technologies

Component Vendors

Creare: Value Added Services For Energy Supplies

- Systems engineering
- Design and analysis
- Thermal
- Electrical
- Power systems
- Fabrication
- Testing
- Commercialization

OEM Partners (Upgraded Products)

End Users (Utilities, Military)

SiC, 1.2 kV, 500 A

SiC, 1.2 kV, 1,000 A

SiC, 10 kV, 25 A
Dynapower: Grid-Tied Energy Supplies

IPS-500
500kW, 480VAC

POWERSKID
4.5MW, 13kVAC

Liquid-Cooled Inverter Modules + 60Hz Filters

60Hz Transformer
Use SiC WBG technology to improve the value proposition for Grid Tied Energy Supplies:

- SiC high voltage rating enables direct connection to medium voltage grids (3kθ, 12.47 kV) (*this is the enabling technology*)
- Eliminates 60 Hz transformer (*reduces size*)
- High operating temperature eliminates liquid cooling (*reduces size, improves reliability*)
- Create modular building block for 500 kW to MW* (*expand markets*)
- Achieve >4x power density improvement (*customer benefit*)
- Reduce audible noise (*customer benefit*)

**Proposition:** SiC devices can improve the value of grid tied energy supplies by reducing size and cost and improving reliability and end user satisfaction.
Opportunity for Improvement

Limitations of this design:

• Requires 480 : 12.47 kV transformer for grid connect.
• Silicon MOSFETs or IGBTs require liquid cooling (~ 50°C).
• Filter is large and also requires liquid cooling.
• 60 Hz transformer emits acoustic noise.
**SiC Enables Direct Grid Connection**

**Improvements:**
- SiC MOSFETs enable direct grid connection to 12.47 kV.
- 60 Hz transformer replaced with (2) smaller (10X) high frequency transformers.
- Transformer is quieter.
- Liquid cooling is eliminated.
- Filter faces lower current, reduces losses and eliminates liquid cooling.
Cost is Roughly the Same: SiC vs. Si

System level per unit material costs are comparable ($141K vs. $152K). SiC MOSFET costs are higher than Si IGBTs, but magnetics and cooling costs are lower. **SiC costs are likely to reduce.**

**Notes:**
- HV SiC MOSFETs require (3) parallel
- HV Si IGBTs require (2) series
Size is 4.3X Smaller: SiC vs. Si

Size of the inverter which uses SiC MOSFETs is much smaller, with 4.3X power density.
Long Term Objective:
Greater Power Density and Revenue

Our long-term objective is to provide the API to improve existing products.

Existing 500 kVA Grid Tied Energy Storage Container (Dynapower)

Key:

- **Eliminate**
- **Add**

**Nominal Existing Generation System**

- 500 kW, 250 kW-hr
- 23 x 8 x 10 ft.
- Includes AC & DC switchgear
- Optional: solar recombine (600 – 1000 V PV arrays)
- Optional: 4 x 2 x 4 ft. 480:480 transformer
- 3 x 7 x 10 ft. 250 kW-hr Li-ion battery
- Ramp rate control, frequency regulation, VAR support
- Seamless dynamic transfer
Benefits Summary

Smaller size leads to lower installation costs and simpler logistics. Reliability is better and audible noise is reduced.

<table>
<thead>
<tr>
<th>Creare’s API:</th>
<th>Features, Advantages and Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Technical Feature</strong></td>
<td><strong>Competitive Advantage</strong></td>
</tr>
<tr>
<td>SiC MOSFET based inverter</td>
<td>• Higher operating temperature and voltage than Si</td>
</tr>
<tr>
<td>Transformerless, convection</td>
<td>• Smaller size, simpler design, higher reliability</td>
</tr>
<tr>
<td>cooling</td>
<td></td>
</tr>
<tr>
<td>12.47 kV, &gt; 1 MW+</td>
<td>• Direct connection to 12.47 kV grid, greater power</td>
</tr>
<tr>
<td>Renewables interface</td>
<td>• Enables larger batteries, solar, wind in one container</td>
</tr>
</tbody>
</table>
Acknowledgments

• DOE Office of Electricity
• Dr. Imre Gyuk
• Dr. Stan Atcitty

Thank you!

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<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requirement</th>
<th>Creare’s API</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semiconductor Type</td>
<td>Silicon Carbide</td>
<td>Silicon Carbide</td>
</tr>
<tr>
<td>Output Voltage (kV)</td>
<td>&gt;12.47</td>
<td>12.47</td>
</tr>
<tr>
<td>Output Power (kW)</td>
<td>100</td>
<td>500 (can be combined for MW+ class power)</td>
</tr>
<tr>
<td>Power Density Improvement</td>
<td>2X</td>
<td>4.3X</td>
</tr>
<tr>
<td>60 Hz Transformer</td>
<td>Eliminate</td>
<td>Eliminated</td>
</tr>
<tr>
<td>Cooling</td>
<td>Eliminate liquid cooling</td>
<td>Forced air convection</td>
</tr>
<tr>
<td>Power Flow</td>
<td>Bidirectional</td>
<td>Bidirectional</td>
</tr>
</tbody>
</table>
DAB and 3LNPC: Pros and Cons

• Pros
  – Reduced stress on primary side.
  – Two simpler transformers -- can be on same core if desired. Each has 1/2 the total power.
  – Independent DABs can regulate 10 kV DC buses for 3LNPC.

• Cons
  – More switches, increased complexity.
Phase I Accomplishments: Packaging

Existing Silicon IGBT Power Assembly. Volume of this power assembly is 1.3 m$^3$ and total inverter volume is 4.6 m$^3$.

Creare’s SiC API. Volume is 1.1 m$^3$ and 4.3 times higher power density than the silicon IGBT design.
Inverter Size Comparison. Creare’s API is much smaller than existing inverters and does not require a large 60 Hz transformer to achieve 12.47 kV.

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Size (m³)</th>
<th>Voltage</th>
<th>Power (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creare</td>
<td>1.1</td>
<td>12.47 kV</td>
<td>500</td>
</tr>
<tr>
<td>Dynapower (Si)</td>
<td>4.6</td>
<td>480 V</td>
<td>500</td>
</tr>
<tr>
<td>Advanced Energy AE500NX</td>
<td>4.8</td>
<td>480 V</td>
<td>500</td>
</tr>
<tr>
<td>Solectria SGI500</td>
<td>5.9</td>
<td>208 V</td>
<td>500</td>
</tr>
<tr>
<td>SMA America Sunny Central 500</td>
<td>7.0</td>
<td>480 V</td>
<td>500</td>
</tr>
<tr>
<td>Satcon Tech. PVS500</td>
<td>9.4</td>
<td>480 V</td>
<td>500</td>
</tr>
</tbody>
</table>

Note that existing inverters have 480 V or 208 V outputs, which requires an additional transformer, such as the Temco medium voltage transformer (480:12.47 kV, three phase 500 KVA, 5.3 m³, $32,000) to achieve 12.47 kV. This roughly doubles the required size and substantially increases cost.
## Technology Deployment Plan

### 10 Year Plan for Deploying the API

<table>
<thead>
<tr>
<th>Development Phase</th>
<th>Time Frame</th>
<th>Objectives/Technical Focus</th>
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<tbody>
<tr>
<td>SBIR Phase I</td>
<td>2015–2016</td>
<td>• Develop proof-of-concept system</td>
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<td></td>
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<td>• Feasibility testing</td>
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<td>SBIR Phase II</td>
<td>2016–2018</td>
<td>• Full-scale prototype demonstration</td>
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<tr>
<td></td>
<td></td>
<td>• Refine business plan</td>
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<tr>
<td></td>
<td></td>
<td>• Marketing to existing and new customers</td>
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<tr>
<td></td>
<td></td>
<td>• Evaluate peak shaving, energy shifting, ramp rate mitigation, frequency regulation, active VAR management, voltage control</td>
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<tr>
<td>Commercialization</td>
<td>2018–2025</td>
<td>• Conduct initial demonstrations</td>
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<td>• Low volume production</td>
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<tr>
<td></td>
<td></td>
<td>• Obtain safety certification</td>
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What Motivates This Technology?

Use SiC WBG technology to improve the value proposition for Grid Tied Energy Supplies:

- Cover the entire conversion process from energy storage to electric utility connection in one container (simplifies installation and reduces cost)
- SiC high voltage rating enables direct connection to medium voltage grids (3φ, 12.47 kV) (this is the enabling technology)
- Eliminates 60 Hz transformer (reduces size)
- High operating temperature eliminates liquid cooling (reduces size, improves reliability)
- Create modular building block for 500 kW to MW+ (expand markets)
- Achieve >2x power density improvement (customer benefit)
- Reduce audible noise (customer benefit)

**Improve the Value Proposition:** For utilities and energy consumers who want to reduce the cost and improve the reliability of power delivery while expanding renewable energy capabilities, Creare’s Advanced Power Inverter (API) will reduce equipment size and cost, simplify thermal management requirements, and improve harmonic performance.
The Enabling Technology: SiC Devices

Advantages
- Higher operating temperature than silicon devices
- Higher operating voltage than silicon
- Enables direct utility connection
- Eliminates 60 Hz transformer
- Eliminates liquid cooling

Disadvantages
- Less mature than silicon devices
- Higher per unit cost than silicon devices

**Proposition:** SiC devices can improve the value of grid tied energy supplies by reducing size and cost and improving reliability and end user satisfaction.