Highly Efficient, High Power Density GaN-based DC-DC Converters for Grid-Tied Energy Storage Applications

Department of Energy Phase I SBIR

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SBIR Program Goals and Timeline

Design and develop a high efficiency (>98%) power dense (>10 kw/L) bidirectional GaN based DC-DC converter for energy storage applications

**Phase I**
- **2014**
  - Develop a general hardware platform capable of using GaN, SiC, and Si
  - Start Program

**Key Deliverables:**
- GaN DC-DC converter demonstrator and design

**Phase II**
- **2015**
  - Evaluate the benefits of GaN and begin Ph. II design

**Key Deliverables:**
- Design, build and test a >50 kW DC-DC for use in ESS

**Phase III**
- **2016**
  - Interface converter between battery storage and Grid-tied inverter

**Key Deliverables:**
- >50 kW DC-DC Converter

- **2017**
  - Fully qualify DC-DC converter for use in commercial applications

- **2018**
  - APEI, Inc. will work with its partners to transition this DC-DC converter technology to a commercial product

- **2019**
Program Target Applications

• Residential and light commercial (<10 kw)
  – Renewable energy storage and interface converter
  – Hybrid Electric/Electric vehicle

• Industrial (10 kW to MW scale)
  – Renewable energy storage and interface converter
  – Uninterruptible power supplies
  – Hybrid Electric/Electric heavy vehicle (locomotives, heavy machinery)
Power Electronics and Energy Storage Markets

Power Electronics Market
• < 900 V – GaN set to grow greatly in this area. GaN has the potential to offer higher performance and lower cost.
• > 1.2 kV – Currently, ideal Area for SiC; GaN research being done to penetrate this market

Energy Storage Market
• The global energy storage market is expected to grow from $39.7B in 2011 to $61.9B by 2016 at an annual growth rate of 9.3% [1]

Advantages of GaN

- Extremely fast switching which enables:
  - Smaller/less expensive filtering elements
  - Lower switching loss increases efficiency and reduces cooling requirements
- Cascode arrangement enables:
  - Simple drive requirements (Si MOSFET front end)
  - Usable anti-parallel diode
- GaN on Si enables lower cost than SiC
Need for High Efficiency DC-DC Converters in Energy Storage Systems

- High efficiency DC-DC converters provide critical functionality in energy storage systems:
  - They provide galvanic isolation (safety)
  - They are inherently capable of providing circuit breaker functionality
  - They interface the inverter to the batteries
  - They control the charging/discharging of batteries
- **High efficiency is critical and can significantly decrease wasted energy, operational cost, and payback period**
Need for Bidirectional Power Flow

Power Flow to Grid

Battery System → DC-DC Converter → DC-AC Converter (Inverter)

Power Flow to Battery

Battery System → DC-DC Converter → DC-AC Converter (Rectifier)
Technical Approach

- Dual Active Bridge (DAB) topology
  - Power bidirectional
  - Soft switching topology decreases switching loss
  - High frequency isolation transformer enables galvanic isolation in a small volume
  - Scalable from 100’s of watts to MWs

- Modular approach
  - GaN, SiC, and Si full bridges will be constructed to evaluate the each devices performance
Device Comparison

• Since they DAB introduces a logical split between primary and secondary different devices can be compared easily:
  – GaN/GaN, SiC/SiC, Si/Si, GaN/SiC, GaN/Si, SiC/Si

• Multiple configurations will be tested for efficiency to determine how each device can benefit the system
Initial Simulation Results

![Output Power vs. Efficiency](image)

- **Si**
- **SiC**
- **GaN**
Hardware Prototype

• The full bridge (pictured right) is used as one half of the dual active bridge. Each full bridge uses either 4 : 40 mΩ SiC MOSFETs, 40 mΩ Si MOSFETs, or 45 mΩ GaNFETs

• The control board pictured right will sense voltages and currents and provide feedback control by controlling the gating signals of the full bridge boards
Phase I Tasks

• Converter Design
  – Finalize specifications (complete)
  – Parts selection (complete)
  – Design and build (in progress)
  – Testing and optimization

• GaN Power Module Design
  – Device and material selection
  – Layout design
  – Thermal/Mechanical/Electrical simulation
Summary

• High efficiency bidirectional DC-DC converters are critical for current and future energy storage systems
• GaN transistor technology can greatly improve efficiency compared to Si technology
• The DC-DC converter demonstrator deliverable for Phase I is nearly complete and awaiting testing
• Once complete, a higher power (>50 kw) design for Phase II will begin utilizing a custom GaN power module
Questions?