GaN-based High Frequency Link Converters for Grid-Tied Energy Storage Applications

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Contents

- Project Team – FSU, Transphorm & PPS
- Project Steps
- Project Overview
- Motivation & Objective
- Applications of GaN in Energy Storage
- DC-DC Module Design
- Simulation Results & Performance
- Summary
Princeton Power Systems designs and manufactures state-of-the-art technology solutions for:

• **Energy Management (Energy Storage, Photovoltaic, Backup)**
• **Microgrid Control and Operations**
• **Bi-directional Electric Vehicle Charging**

We are a global leader working with customers and partners across North America, Europe, Africa and the Caribbean. Our UL and CE-certified power electronics are used in advanced battery operations and alternative energy, with built-in smart functions for ancillary services. We also build customized, integrated systems and design, commission and operate microgrids. Based in New Jersey, we proudly manufacture our products in the USA.
FSU/PE group has rich experience about WBG devices application in grid-connected PV converters. The group has successfully developed GaN based PV Module-Integrated Converter (MIC) and SiC based high power PV converters for grid-interactive application to achieve high power density and high power efficiency. The high frequency operation performance of GaN and SiC devices has been investigated and evaluated.
Transphorm Gallium Nitride (GaN) Switches provide significant advantages over silicon (Si) Superjunction MOSFETs with lower gate charge, faster switching speeds and smaller reverse recovery charge. GaN Switches exhibit in-circuit switching speeds in excess of 150 V/ns and can be even pushed up to 500V/ns, compared to current silicon technology usually switching at rates less than 50V/ns.
Project Steps: Overall Project Goals (Phase I & II)

- **Phase I**: Design 60kW inverter for grid-tied storage applications
  - Base design on existing transformer based PPS inverter
  - Achieve early objectives of reducing size and audible noise
  - Incorporate DC side isolation by using Dual-Active-Bridges using GaN devices
  - Demonstrate DAB functionality

- **Phase II**: Build prototype inverter
  - Improve existing designs with enhancements from Phase I
  - Demonstrate grid-tied energy storage using GaN and validate to targets
Motivation: Why are we doing this?

- **Technology Development**
  - Enabling technology – remain market leader
  - Demonstrate use of wide-band-gap devices in a real applications
  - Allow wide band-gap devices to become financially attractive on energy storage systems

- **Product / Application Development**
  - Reduce cost & size of Products
  - Reduce installation costs
  - Improve efficiency
  - Reduce audible noise
Objectives: Phase 1

- >600V DC-link voltage
- >50kW power
- 480VAC output three phase grid tied
- High junction temperature
- High frequency link frequency of >15 kHz
- 2% more efficient than the existing transformer based inverters
- 40% increase in power density
Approach: A GaN Application

Upgrade existing product to meet objectives
Approach: A GaN Application – Product Upgrade

Application: Upgrade of Existing Product
- Grid-tied inverter for Energy Storage
  - Double Conversion (DC->DC->AC)
  - 2-level PWM AC & DC stage
  - 6 kHz switching frequency
- 10 Year Proven Technology
- Often used with 60 Hz Isolation Transformer

- Upgrade: High-frequency DC-DC
  - Proven in lab at FSU
  - Drastically decreases size of DC port components

- Built-in galvanic isolation
  - Eliminates grid-side transformer, increasing overall system power density
DC-DC Design: Switch Selection - GaN HEMT

- High Switching Frequency: 10x of Si devices for smaller $Q_g$, $C_{gs}$ & $Q_{rr}$
- Low $R_{ds_{on}}$: $V_B^2/R_{on}=5000$ (40 for Si)
- High temperature operation > 200 C
- Third quadrant operation: Eliminates free-wheeling diode
- Normally-off operation: Safe for high voltage/power

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*Per switch*
DC-DC Design: Transformer Selection - Planar Transformer

12 KW Planar Transformer Design

12KW Transformer:
4 Turns Primary
6 Turns Secondary
8 layer 4 oz PCB
0.26 Tesla
Losses: 154 mW/cm³
Ferroxcube 3F3

5uH Planar Inductor Design

Main Inductance:
5uH
31A RMS
6 turns
8 layer 4oz PCB
Ferroxcube 3F3
Simulation Results & Performance

- Using Pspice Engine (OrCAD)
- Transphorm Device Spice Models
- 12 kW stage (5 stages for 60 kW design)
- Device is rated for 12 A at 100°C and 17 A at 25°C
- Transformer inductance and output capacitance is based on 12KW DC-DC design
Simulation – DC-DC steady state (300kHz)

- 98% efficiency
- Output 12 kW
- Ids average 13A
- 450 Vin
- 700 Vout
Simulation Results & Performance

Power rating modules vs efficiency

Volume breakdown of DAB module

Operating frequency of modules vs efficiency

Outcome for DAB design
– 5x 12kW modules (60kW)
– 300kHz switching freq.
Simulation Results & Performance

Breakdown of Losses

Losses from:
- Switch losses (Conduction & Switching)
- Transformer loss
- Inductor losses
- Capacitor loss

Simulated efficiency curve of DAB module (DC-DC stage only)

Simulated RMS current per Power Module

- 20 kW x 3
- 15 kW x 4
- 12 kW x 5
- 10 kW x 6
Summary

GaN Inverter Design & Simulations
- For Grid Tied Application (Storage & EV Charging)
- Switching frequency 300kHz
- DC-DC Energy Density 100W/in³
- 60kW Power (By Modular Approach)
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Thank you

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