PRINCETON POWER SYSTEMS
Clean Power Made Simple™

2015 DOE OE Energy Storage Program Peer Review

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

(SBIR Phase I – DOE Energy Storage Program, Dr. Imre Gyuk and Technical POC Dr. Stan Atcitty, Sandia National Laboratories)

U.S. DEPARTMENT OF ENERGY

Sandia National Laboratories

EESAT TECHNICAL CONFERENCE | SEPTEMBER 21-25, 2015 PORTLAND, OREGON

Martin Becker
Princeton Power Systems

princetonpower.com | info@princetonpower.com | @PrincetonPower1

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-SC0011946.

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

Project Team: PPS

PRINCETON POWER SYSTEMS

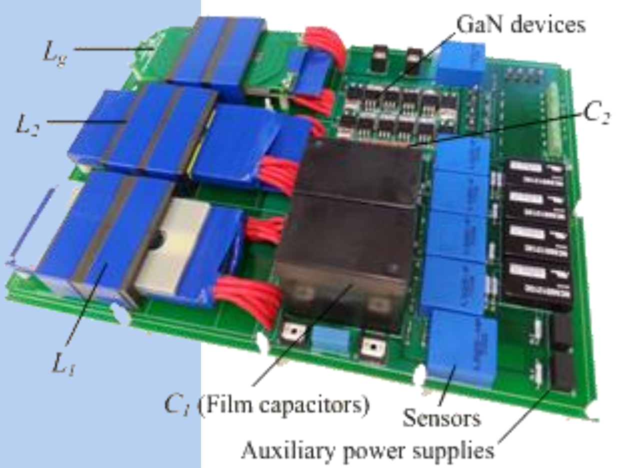
Princeton Power Systems designs and manufactures state-of-the-art technology solutions for:

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

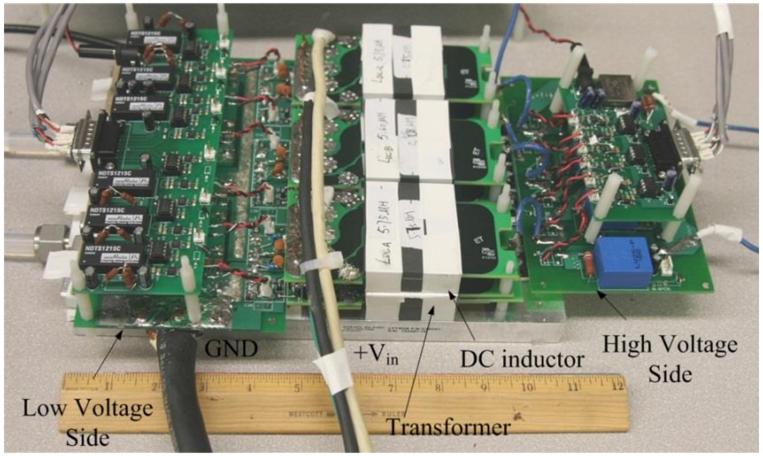
We are a global leader working with customers and partners across North America, Europe, Africa and the Caribbean. Our UL and CE-certified power electronics are used in advanced battery operations and alternative energy, with built-in smart functions for ancillary services. We also build customized, integrated systems and design, commission and operate microgrids. Based in New Jersey, we proudly manufacture our products in the USA.

Project Team: Florida State University/PE Group

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.



GaN based Module-integrated PV converter

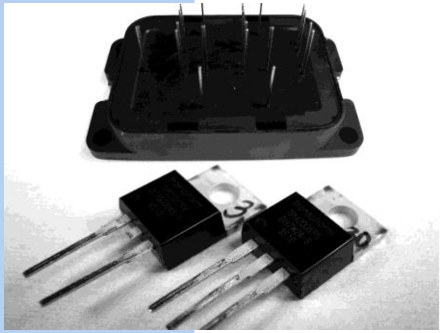


Three-port 5kW grid-tie PV converter

Project Team: Transphorm – GaN Technology

Transphorm Gallium Nitride (GaN) Switches provide significant advantages over silicon (Si) Superjunction MOSFETs with lower gate charge, faster switching speeds and smaller re-verse 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.

Discretes & Modules



Application demos

transphorm

PRINCETON POWER SYSTEMS
Clean Power Made Simple™

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 ?

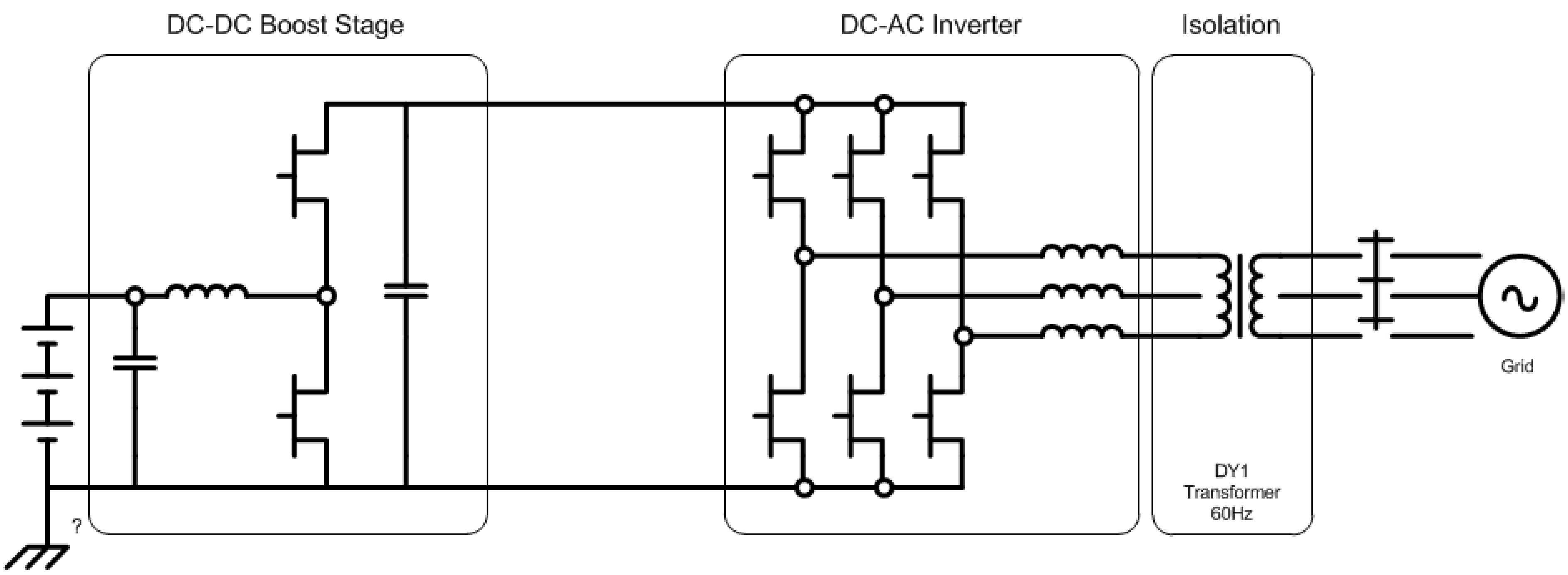
- **Technology Development**
  - **Enabling technology – remain market leader**
  - **Demonstrate use of wide-band-gap devices in a real applications**
  - **Allow wide band-gap devices to become financially attractive on energy storage systems**

- **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



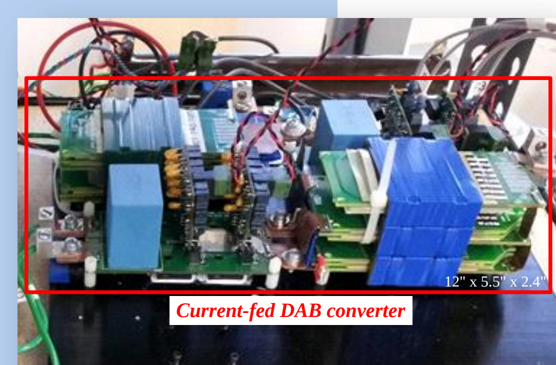
Upgrade existing product to meet objectives

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



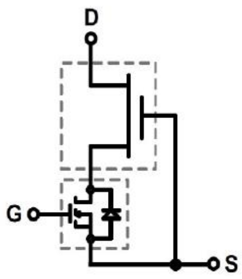
- Upgrade: High-frequency DC-DC
  - Proven in lab at FSU
  - Drastically decreases size of DC port components

- Built-in galvanic isolation
  - Eliminates grid-side transformer, increasing overall system power density

DC-DC Design: Switch Selection - GaN HEMT

transphorm

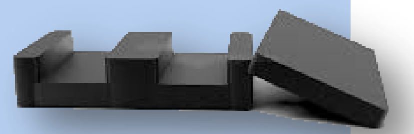
- High Switching Frequency : 10x of Si devices for smaller Q_g, C_{gs} & Q_{rr}
- Low R_{ds_on}: V_B^2/R_{on}=5000 (40 for Si)
- High temperature operation > 200 C
- Third quadrant operation: Eliminates free-wheeling diode
- Normally-off operation: Safe for high voltage/power

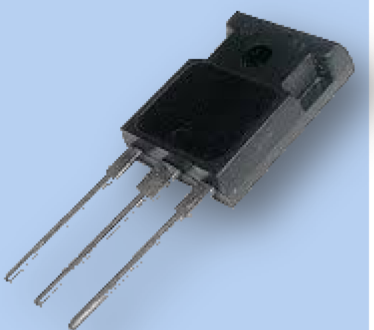


Ron	Vds,max	Imax(pulse)	Imax(CW)
mohm	V	A	A
150	*900*	*60*	*17*
Rth	Qg	Qgs	Qrr
°C/W	nC	nC	nC
0.2	*25*	*320*	*54*
*Per switch			

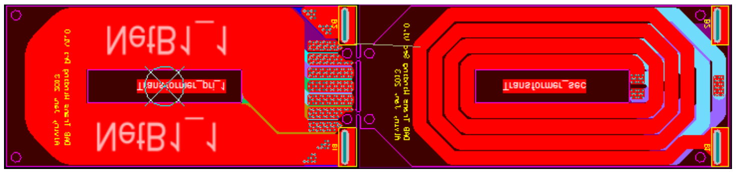
PRINCETON POWER SYSTEMS
Clean Power Made Simple™

DC-DC Design: Transformer Selection - Planar Transformer



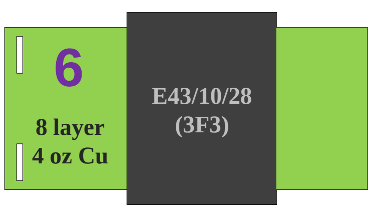


12 KW Planar Transformer Design

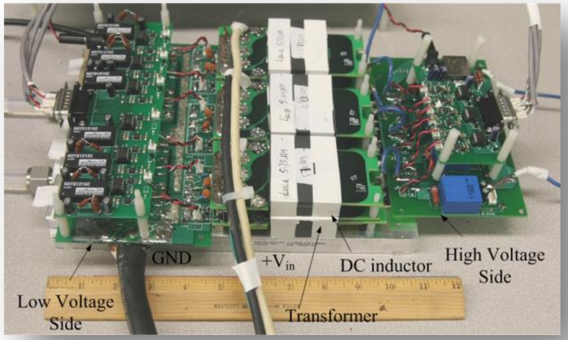


12KW Transformer:
4 Turns Primary
6 Turns Secondary
8 layer 4 oz PCB
0.26 Tesla
Losses: 154 mW/cm^3
Ferroxcube 3F3

5uH Planar Inductor Design



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

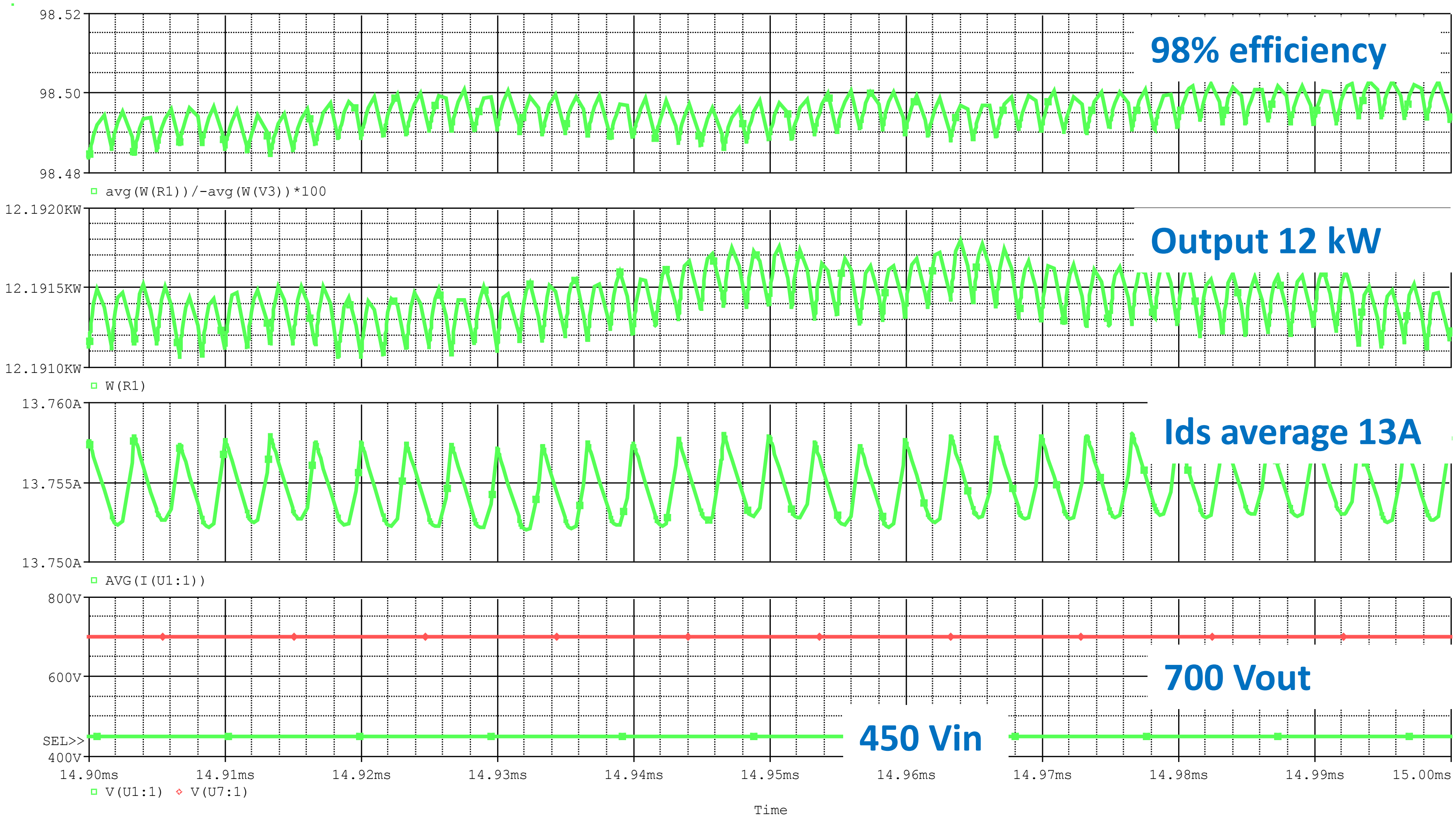


PRINCETON POWER SYSTEMS
Clean Power Made Simple™

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^{o}C and 17 A at 25^{o}C
- Transformer inductance and output capacitance is based on 12KW DC-DC design

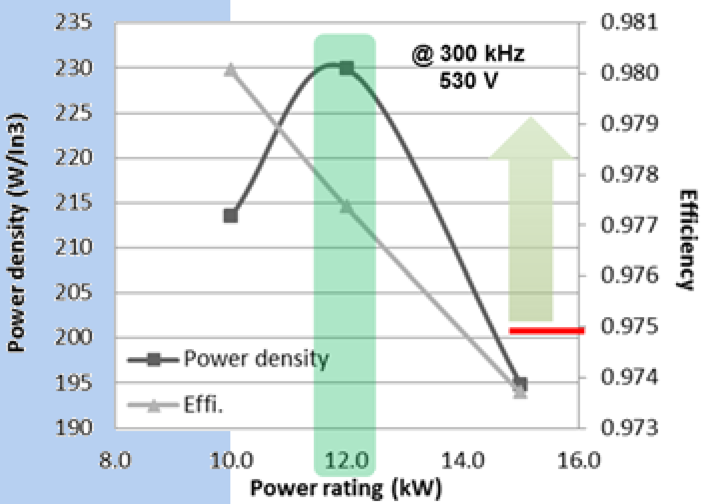
Simulation – DC-DC steady state (300kHz)



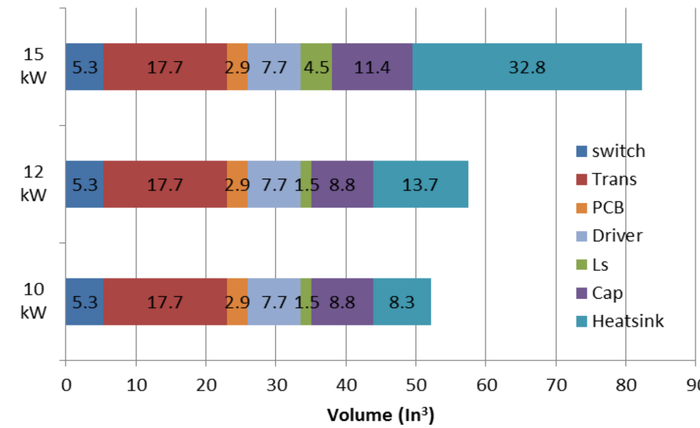
PRINCETON POWER SYSTEMS
Clean Power Made Simple™

Simulation Results & Performance

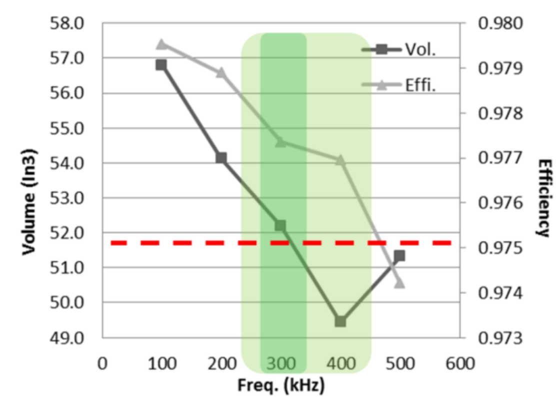
Power rating modules vs efficiency



Volume breakdown of DAB module



Operating frequency of modules vs efficiency

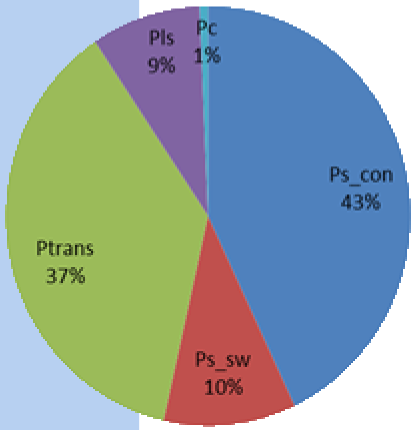


Outcome for DAB design

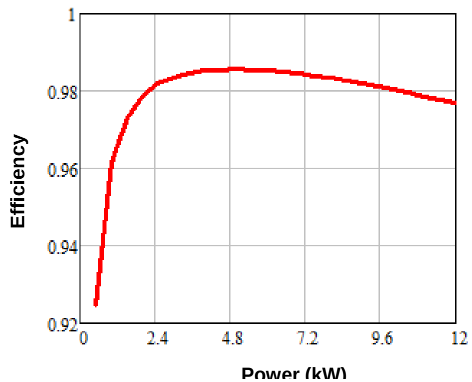
- 5x 12kW modules (60kW)
- 300kHz switching freq.

Simulation Results & Performance

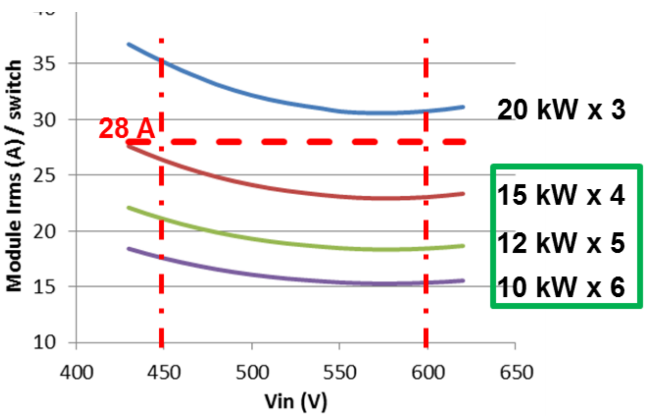
Breakdown of Losses



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



Simulated RMS current per Power Module



Losses from:

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

PRINCETON POWER SYSTEMS
Clean Power Made Simple™

Summary

GaN Inverter Design & Simulations

- For Grid Tied Application (Storage & EV Charging)
- Switching frequency 300kHz
- DC-DC Energy Density 100W/in^3
- 60kW Power (By Modular Approach)

U.S. DEPARTMENT OF ENERGY

Sandia National Laboratories

This project is funded by the DOE Office of Electricity.

We thank Dr. Imre Gyuk for his funding support and Dr. Stan Atcitty for his technical contributions.

Thank you

Martin Becker
mbecker@PrincetonPower.com
www.PrincetonPower.com