Design and Development of a Low Cost, Manufacturable High Voltage Power Module for Energy Storage Systems

Phase I SBIR

September 27, 2012

presented by…

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U.S. DEPARTMENT OF ENERGY

Sandia National Laboratories

- I would also like to thank

BALDOR A MEMBER OF THE ABB GROUP

C&D TECHNOLOGIES, INC. Power Solutions

NORTHROP GRUMMAN

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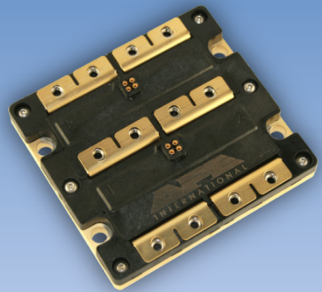
APEI, Inc. Manufacturing Facilities

- APEI, Inc. Class 1000 Manufacturing
- ISO 9001 Certified
- AS 9100 Certified

WCS
AS9100
REGISTERED
Certificate No. AS 0076

Engineering Samples

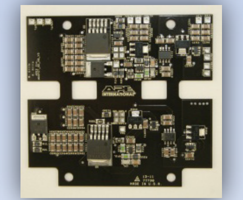
APE XT-1000 series
SiC Power Modules



APE XT-254
SiC Discretes

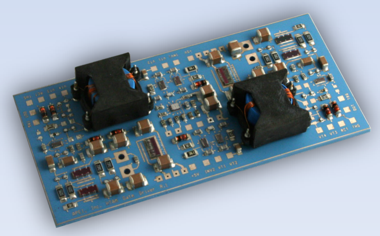
APE HT-2000 series
SiC Power Modules

APE T-2000 series
SiC Gate Drivers



APE HT-DH series SiC Gate Drivers

APE XT- series
SiC Gate Drivers



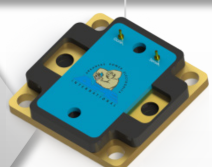
SBIR Program Goals

Design and develop a high performance, high voltage SiC multi-chip power module (MCPM) that targets energy storage applications

Phase I | Phase II | Phase III

2012 | 2013 | 2014 | 2015

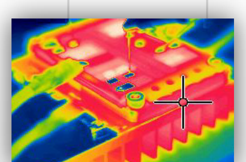
Develop HV packaging approach and demonstrate it via hardware testing



Start Program

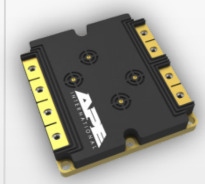
Design HV SiC MCPM based on hardware demonstrator

Key Deliverables: Discrete HV hardware demonstrator and MCPM design



Build and perform electrical, thermal, and reliability testing for the HV SiC half-bridge MCPM

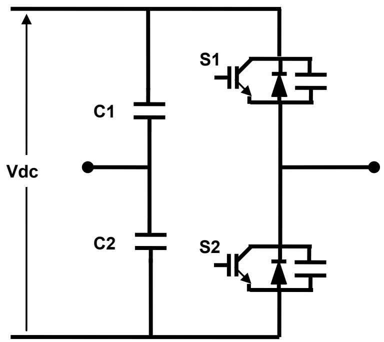
Key Deliverables: High Performance HV Half-bridge SiC MCPMs



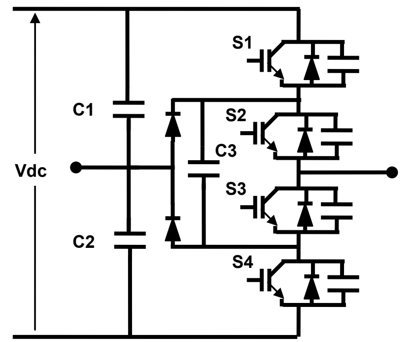
APEI, Inc. will work with its partners to transition this HV MCPM technology to a commercial product

HV SiC Power Modules Reduce Energy Storage System Size and Complexity

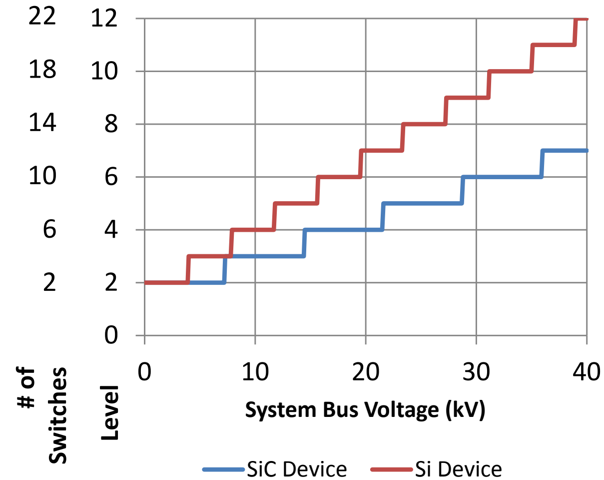
Multi-level converters reduce voltage stress on power devices:



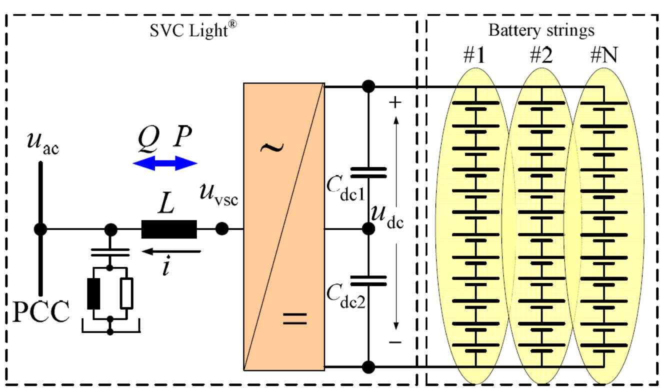
Two-Level Phase Leg
$V_{DS,max} = V_{dc}$



Three-Level Phase Leg
$V_{DS,max} = V_{dc}/2$



ABB's SVC Light energy storage system[1]



Comparison of solutions for a 11 kV 600 kW ESS

Technology	Power Electronics					Relative Size/Mass
	V_{BD}	T_j (°C)	Level	No. Switches	Freq. (Hz)	
Si Device	6.5 kV	125	10	54	900	28x
SiC Device	12 kV	175	6	30	18000	1.4x
SiC Device	12 kV	225	6	30	25000	1x

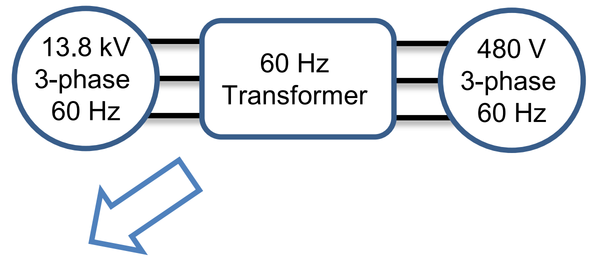
[1] Wade, N., Taylor, P., Lang, P., Svensson, "Energy Storage for Power Flow Management and Voltage Control on an 11kV UK Distribution Network", 20th International Conference on Electricity Distribution, June 2009.

Other Targeted Applications

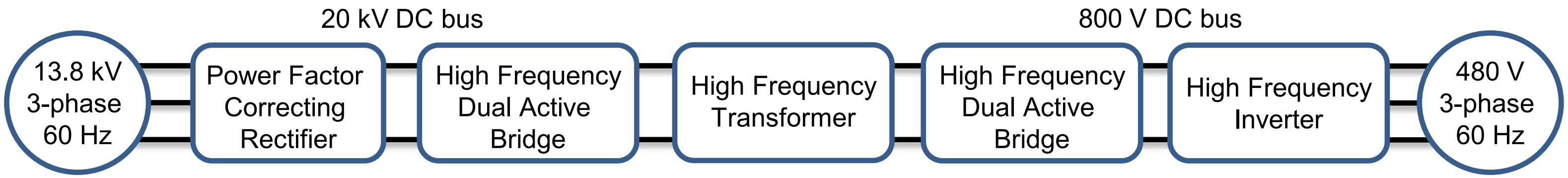
Solid State Transformers

- Replace passive transformers with power electronic converters to reduce size
- Isolation transformer size proportional to frequency

Passive Transformer



Solid State Transformer[2]



Comparison of solutions for a 13.8 kV / 480 V 100 kVA substation transformer

Technology	Power Electronics				Isolation Transformer		
	V_{BD}	T_j (°C)	Level	No. Switches	Freq. (Hz)	Mass (kg)	Volume (m³)
Passive	N/A	N/A	N/A	N/A	60	370	0.480
Si Device	6.5 kV	125	7	70	1000	35.8	0.286
SiC Device	12 kV	175	4	40	17000	10.2	0.057
SiC Device	12 kV	225	4	40	24000	5.32	0.014

70×

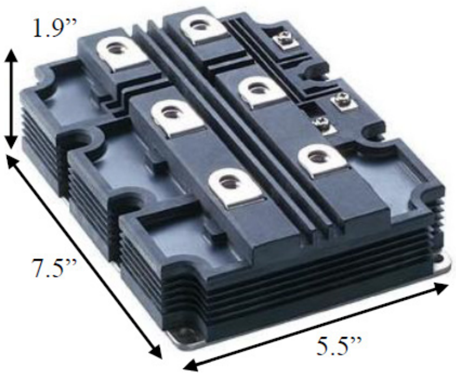
34×

[2] S. Bhattacharya, "15kV SiC IGBT Modules for Grid Scale Power Conversion", ARPA-ADEPT Program, http://arpa-e.energy.gov/LinkClick.aspx?fileticket=Ma9dAocpf2o%3D&tabid=408, (2010).

Existing HV Power Modules vs. Next Generation HV Power Modules

Existing HV Silicon (Si) Power Modules	APEI's HV Silicon Carbide (SiC) Power Module Developed in this SBIR Program
Larger volume/weight than desired	Reduced volume/weight => Simplify system
Limited voltage blocking capability (< 5kV)	High voltage (> 15 kV) capable
Lower switching frequency	Demonstrated high switching frequency
Lower efficiency	Higher efficiency due to low conduction losses
Requires bulky magnetics and filter capacitors	Small magnetics and filter capacitors
Maximum operation temperature is below < 125°C	High operation temperature > 200°C
Higher thermal resistance	Low thermal resistance due to high thermal conductivity of SiC

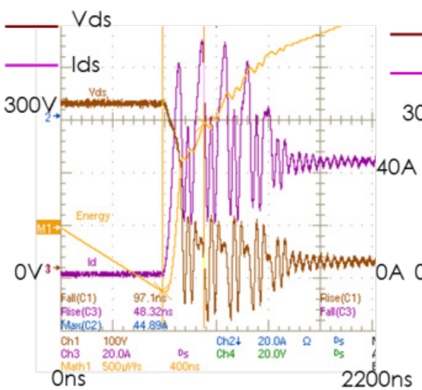
HV Si Single Switch IGBT Module

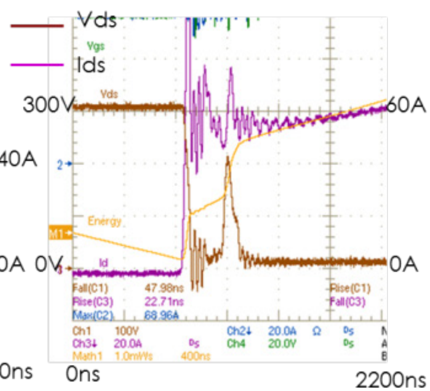


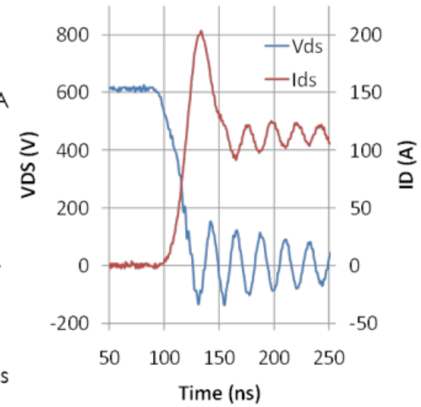
6.5 kV / 750 A, 78 in^3, 1.8 kg

Simply increasing the size of existing Si power modules does not take advantage of the superior properties of SiC

APEI's SiC Power Module Package Design Dramatically Improves Performance

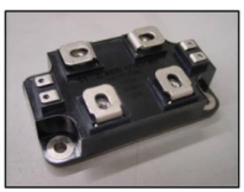






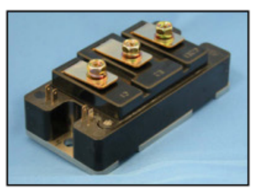
MSK (MOSFET)

- V_{DS} = 300VDC
- I_{DS} = 45 Amps
- Turn On = 47ns
- E_{on} = 2700 μJ @ 300V / 90A



PowerEx (MOSFET)

- V_{DS} = 300VDC
- I_{DS} = 60 Amps
- Turn On = 22ns
- E_{on} = 1600 μJ @ 300V / 90A



APEI HT-2000 (MOSFET)

- V_{DS} = 600VDC
- I_{DS} = 120 Amps
- Turn On = 14ns
- E_{on} = 70 μJ @ 300V / 120A
- E_{on} = 300 μJ @ 600V / 120A

HT-2000

- 22 × reduction in turn off losses
- 17% reduction in on-state resistance
- 20% improvement in thermal resistance
- 50% increase in current capability

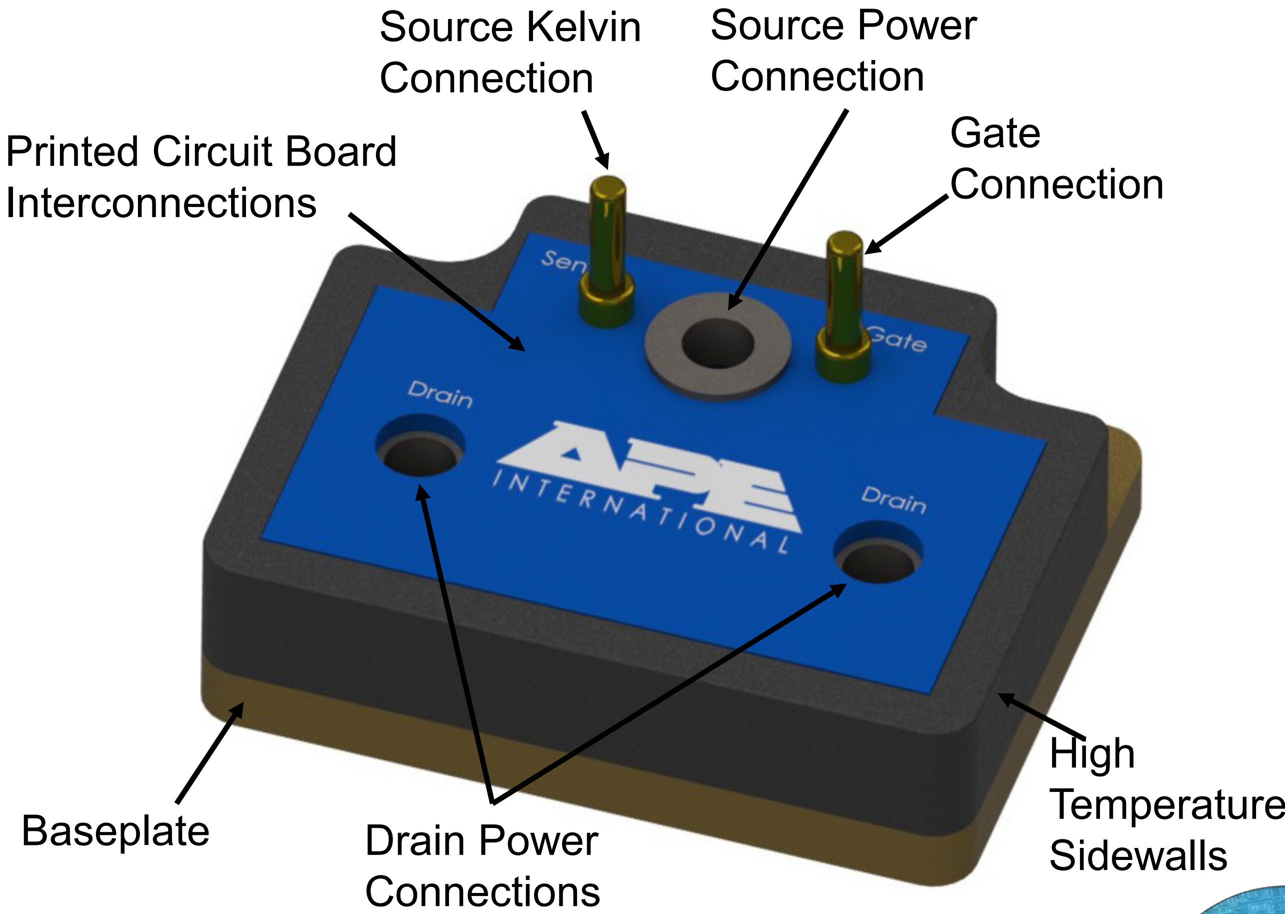
If the power module design is not optimized, switching losses are exacerbated at high voltage

Key Benefits of APEI's HV MCPM Package Design

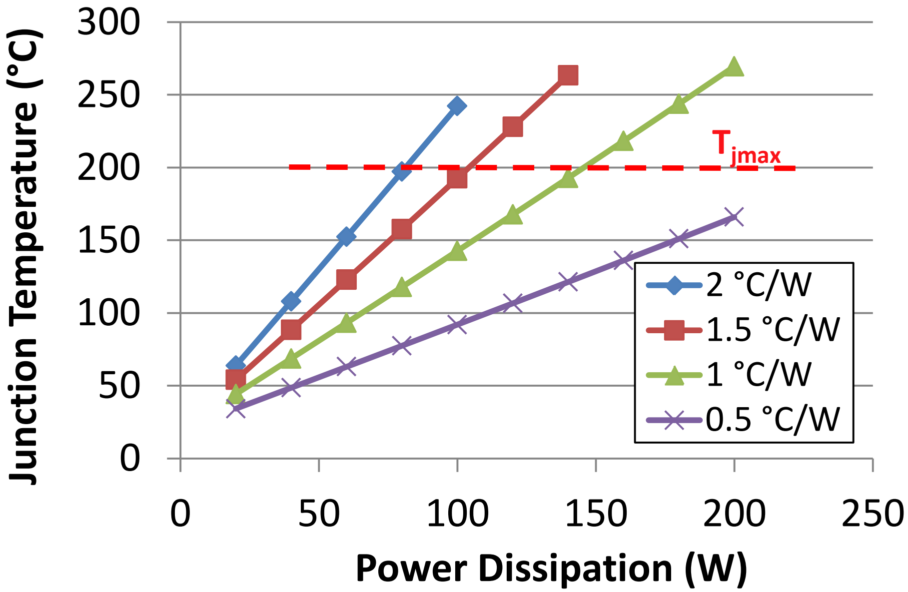
- Low junction-to-case thermal resistance => reduces size of cooling system
- Low module parasitics due to wire bondless interconnections => enables high switching frequency
- Ease of manufacturing
- Reliability
- Reworkability
- Reduction in volume/weight

Discrete Package Will Demonstrate High Performance, HV Package Design

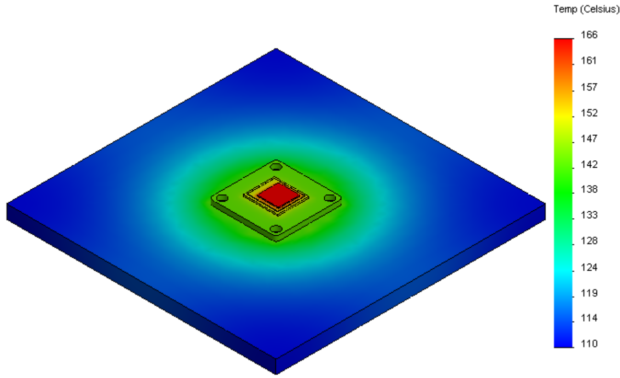
- Device neutral
- High temperature capable (>200°C)
- Low volume
- Low profile
- Wire bondless interconnections
- Improved reliability
- Low resistance and inductance
- Reworkable



Discrete Package Thermal Simulations Demonstrate High Thermal Performance for Passive Cooling



P_{dis} = 200 W, Max Temperature = 166 °C



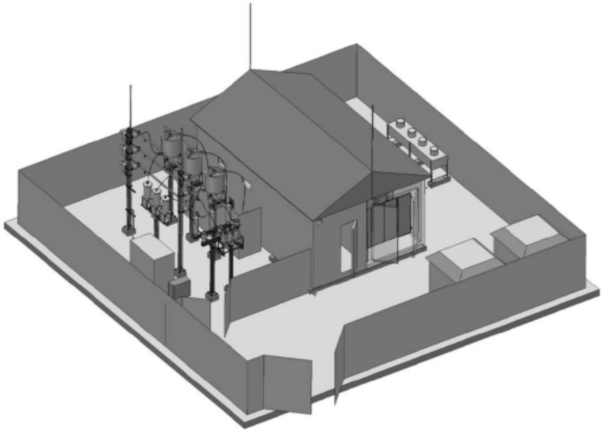
- Passive cooling is possible for 200 W of thermal loss due to the low thermal resistance of the package
- Passive cooling significantly simplifies system

Summary

- Completed HV conceptual discrete package design
- Developed thermal model and confirmed high thermal performance using advanced packaging materials and techniques
- Developed HV design rules
- Targeted applications were identified and analyzed in more detail

Phase I Future Tasks

- Further investigate ESS applications and work with customers to develop target specs
- Finalize HV discrete package design
- Perform full thermal-mechanical stress analysis on packaging approach
- Fabricate, assemble, and test feasibility of packaging concepts
- Perform high voltage electrical parasitic design and analysis and compare with other conventional packaging approaches
- Half-bridge Power Module Mechanical and thermal Design



Questions

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