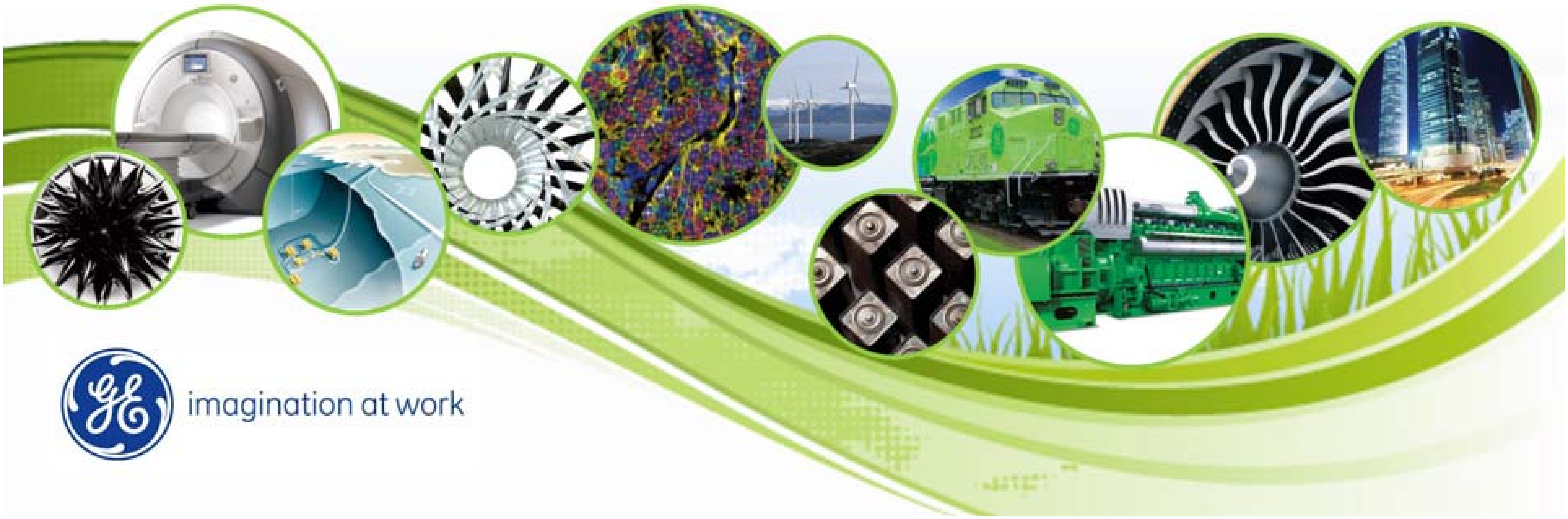
Silicon Carbide
High Voltage, High Frequency Conversion

NIST High Megawatt Variable Speed Drive Technology Workshop

April 2014

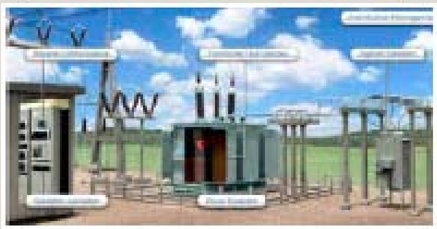
Ravi Raju, GE Global Research



Background

GE Energy Infrastructure

Energy Management



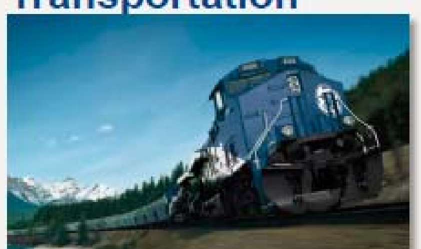
Oil & Gas

Power & Water

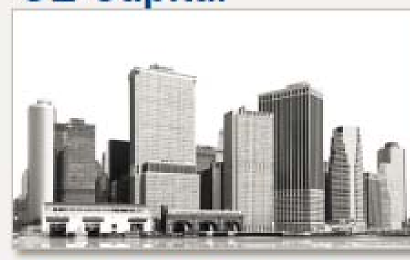
Healthcare

Aviation

Transportation



GE Capital



Home & Business Solutions

GE Global Research - SiC Activities

Internal Efforts

Development of low voltage (1200 V ,1700 V ..) MOSFETs for use in

- Renewables
- Medical systems
- Aviation systems

Collaborative Efforts (partnering with Cree, Powerex, .. ONR, NAVSEA, ARPA-e, NIST)

Application of high Voltage (10 kV) MOSFETs, diodes from Cree/Powerex for:

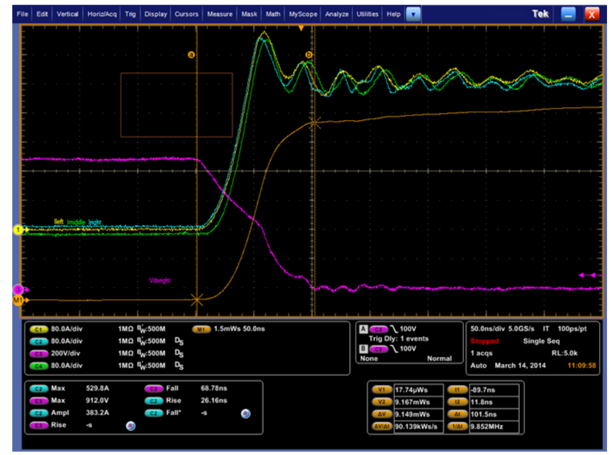
- Navy applications .. SSPS (solid-state power substation program)
- ARPA-e .. multi-terminal HVDC program

GE SiC Devices and Applications

SiC chips (1.2, 1.7kV, ..)

Best-in-Class 1.7kV, 40A MOSFET:

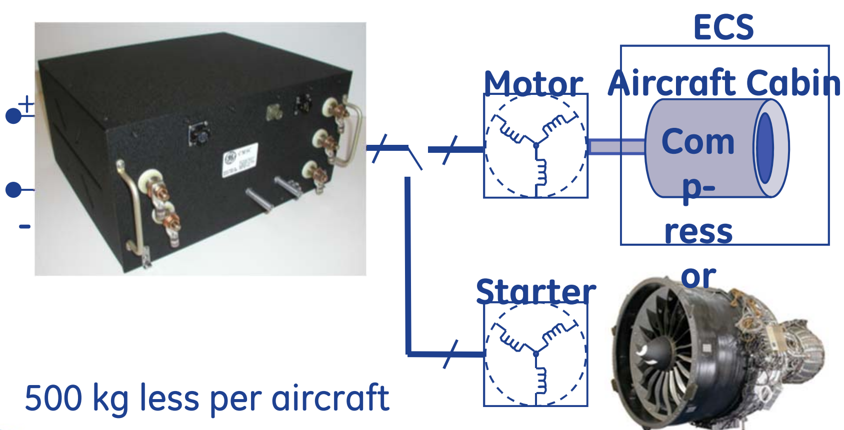
- BV_{DSS} = 1950V
- $R_{DS,On}$ = 36mΩ @ T_j=25ºC
- $R_{DS,On}$ = 60mΩ @ T_j=150ºC
- $R_{On,sp}$ = 5.6mOhm-cm^2



Passed automotive qualification test at 200ºC…AEC-Q101

Applications

75kW SiC inverter for engine start + ECS drive



500 kg less per aircraft

SiC modules

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High Power Electronics (HPE) program – DARPA/ONR Solid-State Power Substation (SSPS)

- Base Program
  - 1 MVA, single phase, 13.8 kVac/ 265 Vac solid-state transformer, 20 kHz link
  - 2007-2009: Development, full-power building blocks tested at GE
  - 2010: Full power testing at NSWC, Philadelphia
- Option Program
  - 1 MW, 4.16 kVac, 3 phase / 1000 Vdc converter, 40 kHz link
  - 1/3rd volume, 1/10th weight of 60 Hz transformer-rectifier
  - Testing ongoing at CAPS-FSU

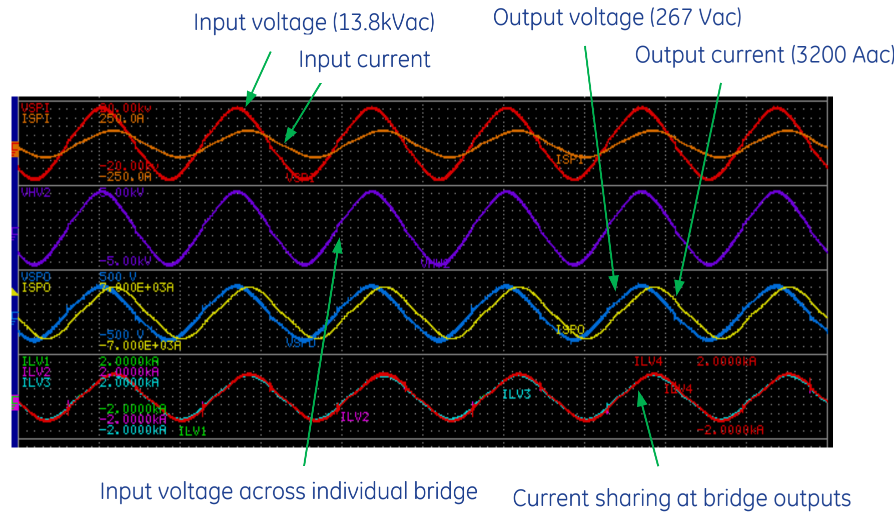
Both projects use 10 kV SiC devices and high frequency transformers

10 kV SiC modules: Cree/ Powerex

HF transformers: Los Alamos, IAP, Dynapower

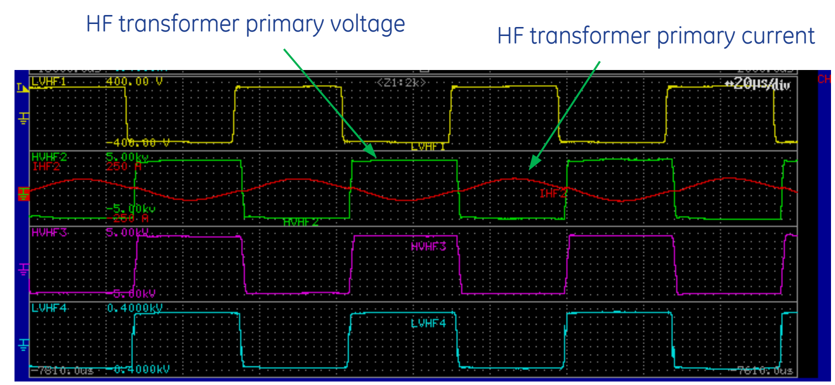
Base Program - SSPS

Single-phase SSPS at Navy test lab



60 Hz waveforms

- ✓ Demonstrated at 1 MVA, 13.8 kV/265 V
- ✓ Efficiency at full load > 97%
- ✓ 1/3rd weight of conventional transformer
- ✓ AC input current/ output voltage THD < 5%



20 kHz transformer primary (HV side) waveforms

Advantages of cabling at higher voltages

13.8 kVac vs. 265 Vac cables carrying same power (1 MVA)

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Option Program - SSPS

Existing 3 W 4160 VAC – 1000 VDC Power Conversion Module

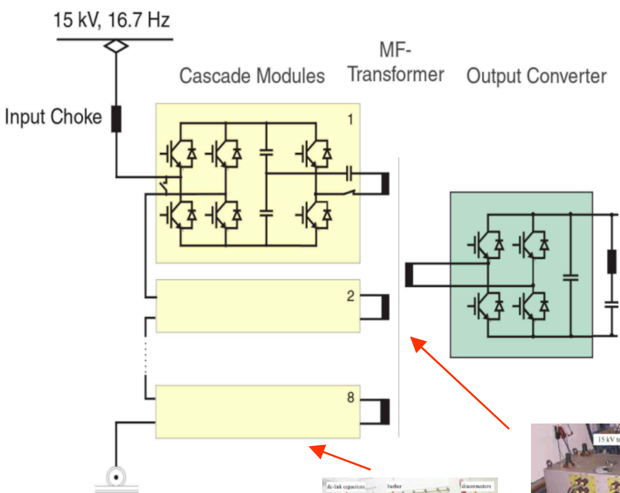
HPE – SSPS SiC 1 MW, 4160VAC-1000 VDC converter

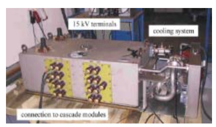
SSPS 1 MW, 4160 Vac- 1000 Vdc tests ongoing at CAPS-FSU

Unit tested to full voltage, … full power testing yet to be done.

Related Activities

(Locomotive Power Electronic Transformers .. ABB, Alstom and others)





Alstom, ABB, …

Input Voltage	15 kV / 16.7 Hz
Output Voltage	1.65 kV
Rated Power	1.5 MW
Overload	2.25 MW / 30s
Efficiency	0.94
Total Weight	3.6 t

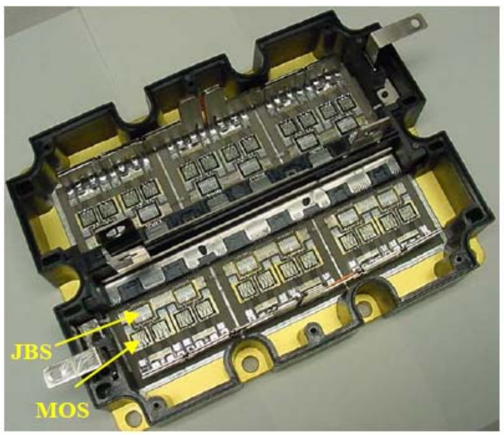
EPE 2003, Alstom/SMA

ABB – installed in 2012

1.2+ MW, 15kVac – 1.5kVdc; 95% efficiency; 10,000 lbs, abb.com

HV SiC Challenges

Example – EMI, dv/dt

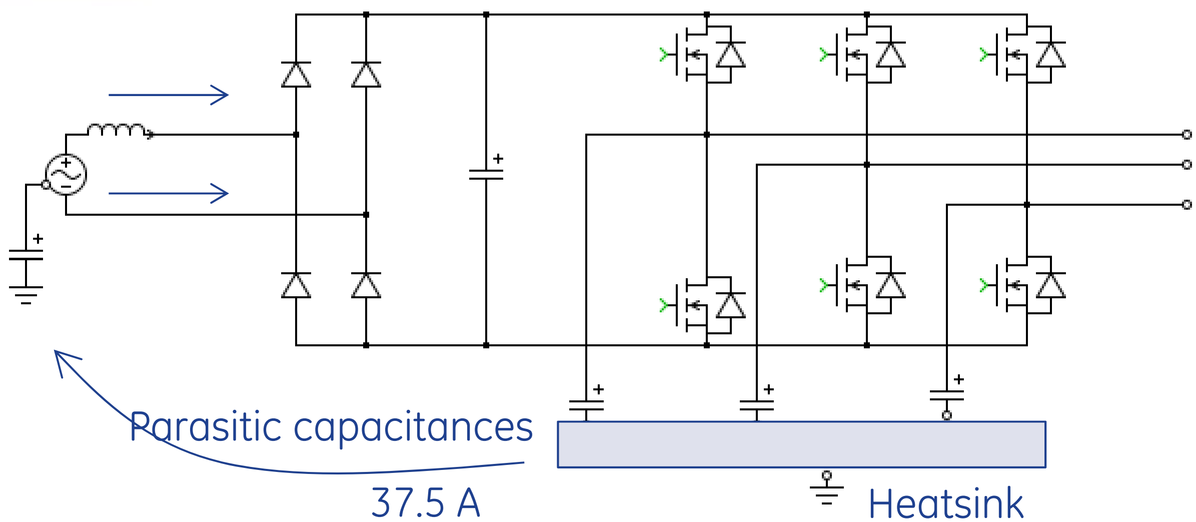


Chips to baseplate capacitance , C ~750 pF

Assume slew rate, dv/dt ~ 5 kV / 100 ns

Common mode current = C. dv/dt = 37.5 amps
(same order of magnitude as rated currents)

Solutions - Decoupling capacitors, synchronized out-of-phase switching of phase-legs to cancel CM currents, etc. can be used.



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Other challenges

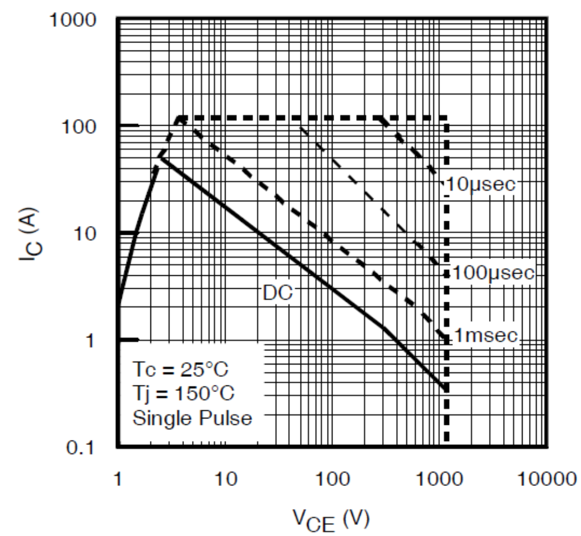
Short Circuit Capability

IGBTs typically rated for > 10 us SC withstand

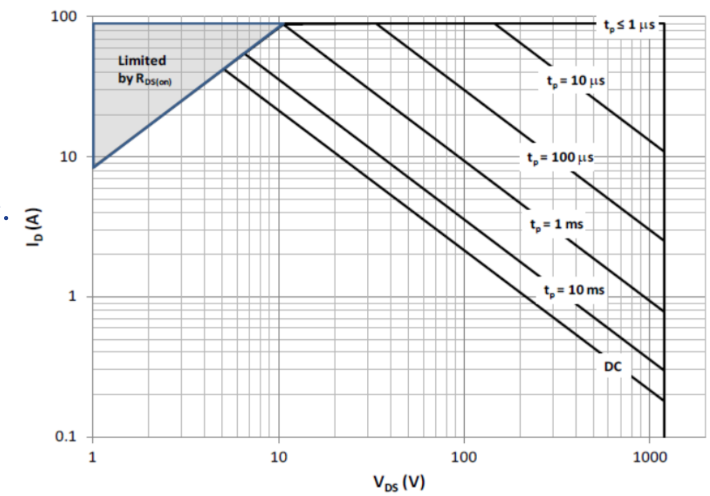
SiC chips with same 'nameplate' current rating are smaller than IGBT chips

- thermal capacity is low.
- lower SC withstand capability

Gate drives/ controls will need faster protection reaction time.



Example 1200 V, 40A IGBT SOA



Example 1200 V, 40A SiC MOSFET SOA

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HV SiC devices or LV building blocks?

10 kV SiC	6 x 1.7 kV Si/ SiC
+ Reduced number of parts (drivers, auxiliaries,..) + Power density benefits of reduced parts	- Higher parts count
+ Simpler controls, no need for balancing	- More complex controls, need for balancing
- Conduction losses/ Rdson increase rapidly with temperature compared to LV MOSFETs;	+ Possibly more efficient?
- limited suppliers, low volumes -> expensive	+ cheaper, wider range of suppliers

Applications for HV SiC

- Data center distribution - MV AC or DC to the rack, (13.8kV distribution to match gensets)

  efficiency, cost benefits, space savings , easier installation

- Transformerless Drives ... where Motor voltage = Grid Voltage

  4160 V, 6.6 kV ... 13.8 kV;

  High switching frequency useful on grid side for power quality, not so needed for motor side

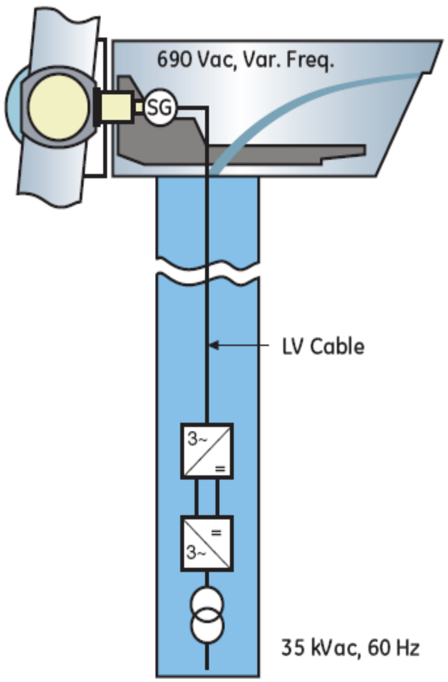
- High frequency transformer-embedded Drives

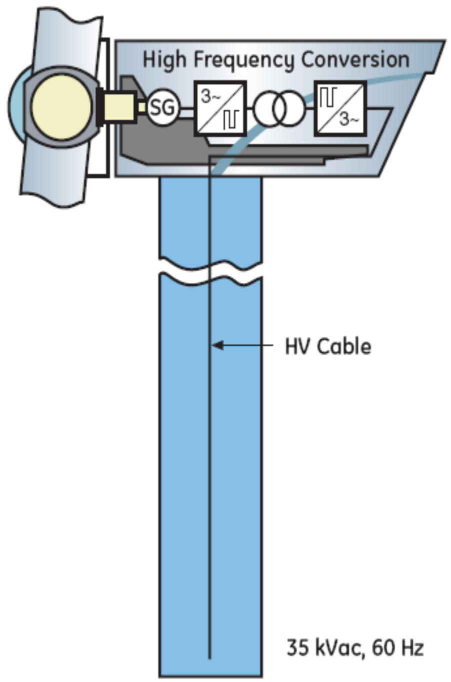
  Mismatch between AC grid and motor voltage , eg, 13.8 kV/ 33 kV supply -> 4160V motor

- Motors operating at high electrical frequencies
  - High speed motors .. O&G compressors 15 k rpm, 5MW, 4160V .. limited volumes?
  - New class of machines with high elec freq .. high pole count... electromagnetic gears ...
- Renewables integration at higher voltage AC/DC.
- Where Power Density counts - locomotives, commercial marine, O&G, Navy, ..

System level cost tradeoffs

Wind example





- Typical present design: converter and transformer are down-tower.
- Cable weight and cost in current turbines is significant due to low voltage (eg, 9,000 lbs for 2.7 MW turbine)
- Up-tower conversion to HV will allow use of lighter HV cables – SiC could enable this.
- Other issues to consider – codes and cost of MV maintenance

	• 2.2 kA, 690 V	45A, 35 kVac
LV vs MV cables	• 6x 500 MCM/ phase • 1.6 lb/ft • 18*1.6*300 ft = 8640 lb. in copper. • 3$/lb*8640 = 26 k $ in copper	1 x 8 AWG sufficient, but limited availability 1/0 cable(200 A), 1000 lbs 3k $ in copper

Thank you

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