SiC Enabled High-Frequency Medium Voltage Drive for High-Speed Motors

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General Electric (GEGR, GERE, GEA, GEEC), UTK, Virginia Tech

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Project Objective

- Develop and demonstrate <u>two</u> SiC-based medium voltage converters for:
  1. 3.8MW Type-3 wind turbine: 6000V-3-60Hz / ~0-750V 3ph ~30-90Hz
  2. 1MW high-speed PM machine 0-1200Hz, 0-1600V
- Achieve: volumetric density <1.4m^3/MW, >97% end-to-end efficiency, eliminate line-frequency transformer
- Achieve >98% efficiency, <5%THD at rated output

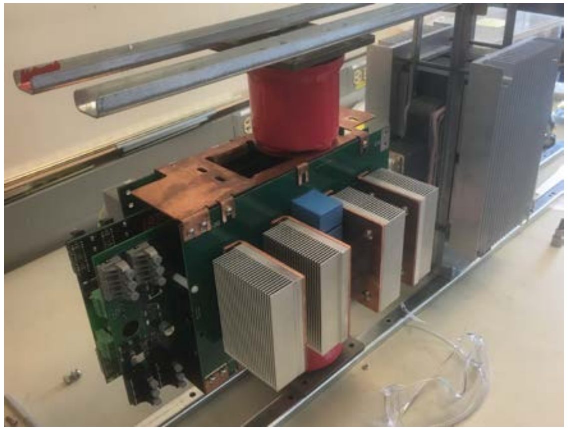
Why is this difficult?

High voltage, low volume, air insulation, control complexity… => iterative design

High converter density requires optimized passives

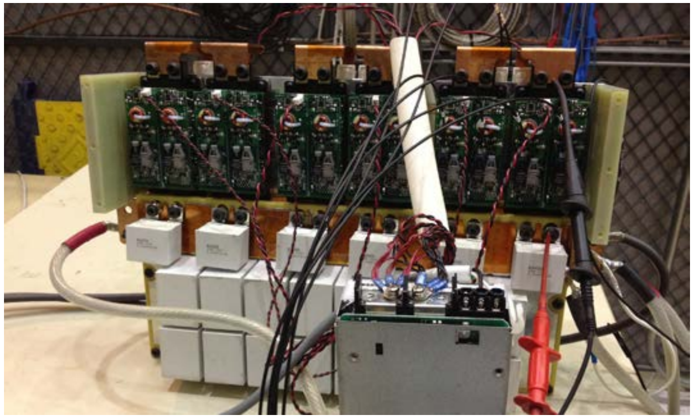
Technical Innovation – Wind Converter

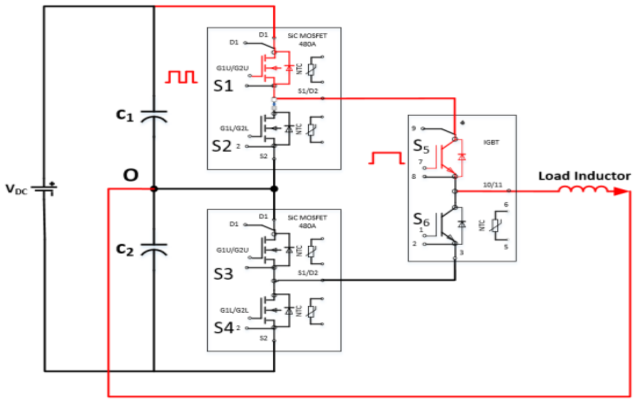
- Today's converters: liquid cooled, 2-level IGBT bridges operating at ~1.2kHz switching frequency
  Converter LxWxH = 0.9x0.5x2.2, V=0.99m^3
  Transformer LxWxH = 1.9x1.3x2.2, V=5.5m^3
  90+ meter LV cable run up-tower
- Replace with an air-cooled, multi-level modular, high-frequency resonant-transformer-insulated converter, occupying <22% of the original volume
- Increase mean-time to forced outage
- Improve converter losses using innovative modulation schemes



Technical Innovation – HF Converter

- Today's system: two, 2-level IGBT converters, with motor windings connected differentially. Voltage controlled by phase shifting converter voltages
- Replace by a single ANPC converter employing a SiC IGBT hybrid in each phase leg
- Improve waveform quality, improve converter efficiency, and simplify motor connections
- Reduce weight and size by minimizing filter components





Technical Approach

Wind Converter

Standardize design around the smaller building block and use granularity to achieve higher functionality: redundancy, higher voltage quality, improved efficiency

Control cost by automating module manufacturing

Improve system reliability by foreseeing failures. Increase monitoring of devices on the gate drive – UTK developing intelligent gate driver

HF Converter

Minimize switching losses by optimizing bridge design, then use the entire loss budget towards increasing switching frequency to minimize filtering requirements

Optimize modulation to achieve THD target

Scale drive ratings by developing stacked power module – VT working on entitlement of switching series connected devices

Transition (beyond DOE assistance)

Wind Converter

Demonstrate control compatibility with the product by lab-testing at GE Wind

Install converter prototype on a wind turbine in late 2018 and operate for up to 6 months

Using final bill-of-materials, develop detailed cost estimates to prove competitiveness

HF Converter

Demonstrate converter performance by driving the propeller load at GE Aviation

Enhance PM motor design to take advantage of higher voltage attainable by SiC converter

Leverage VT work to scale to higher voltages, champion this design for application in MV drives of GE Power Conversion

Measure of Success

Wind Converter

System reliability and cost are the key acceptance criteria for the new converter system

Calculated MTTFF = 1407h, MTTFFO = 8975h
Today's IGBT converter has MTBF = 8143h

The break-even price of SiC is between \$0.28/A and \$0.65/A
Today's SiC projections are \$0.44/A

(Today's IGBTs are at \$0.069/A)

HF Converter

Opens new application spaces, so less sensitivity to device cost

SiC module reliability becomes the key criteria. Hedging device risk by operating 1700V devices at 1200Vdc and at Tjmax < 120C

Ultimately, growth depends on scalability of solutions.
To get system level advantages need modules with Vdcmax >2500V and Tjmax > 200C)

Project Management & Budget

- A 3-year project, structured into 3-budget periods
- Two main thrusts:
  1) Wind converter - entitlement of the modular design (supported by UTK)
  2) HF drive – entitlement of the switching cells (supported by VT)
- Key milestones

Power block test (M6)
Transformer BIL test 60kV (M6)
6kV phase-leg test (M12)
Wind drive tested (M18)
N-1 redundancy tested (M24)
DFIG integration (M27, 30, 33, 36)

ANPC power stage designed & tested (M9, 12)
9000rpm PM motor constructed (M15)
Motor & drive testing (M18, 21, 24, 27)

240A Stacked SiC module development:
1.8kVdc (M6), 3.2 (M12), 6.0 (M18)
6kVdc switch continuous operation (M24)

Total Project Budget	
DOE Investment	$4,999,992
Cost Share	$2,549,593
Project Total	$7,549,585

Results and Accomplishments

- GE at ~M9 of the project, University partners at ~M6
- Meeting efficiency, thermal capability, and BIL
- Meeting target volume on HF drive, currently over target on Wind drive (must change smallest replaceable unit from power block to phase module to get to volume)
- Major effort underway developing protection and control integration of modular converter for Wind
- Streamlining HF transformer mfg. to get to cost
- Construction of HF drive underway
- University partners on track and accelerating
  VT switching 2 devices in series
  UTK testing the baseline gate driver

Progress in Pictures