Fully Integrated High Speed Megawatt Class Motor and High Frequency Variable Speed Drive System

DE-EE0007254

Clemson University and TECO Westinghouse Motor Company

May 1st, 2016 to March 30th, 2020

J. Curtiss Fox, PhD – Clemson University

U.S. DOE Advanced Manufacturing Office Program Review Meeting
Washington, D.C.
June 11-12, 2019

This presentation does not contain any proprietary, confidential, or otherwise restricted information.

Overview Slide

Timeline

- Award issued: May 2016
- Scheduled end date: November 2018
- Projected end date: March 2020
- Project Progress: 85%

Budget

	FY 16 Costs	FY 17 Costs	FY 18 Costs	Total Planned Funding (FY 19-Project End Date)
DOE Funded	1.3M	1.6M	1.7 M	5.09M
Project Cost Share	0.4M	0.6M	0.8M	1.77M

Partners

CLEMSON UNIVERSITY

TECO Westinghouse

Barriers

- Availability of wide bandgap semiconductors in industrial power electronics voltages and currents
- Demonstration of megawatt scale medium voltage high frequency drive systems and high speed induction motors
- Adoption of high speed motor and drive systems for industrial applications
- Costs versus efficiency for complete motor and drive systems

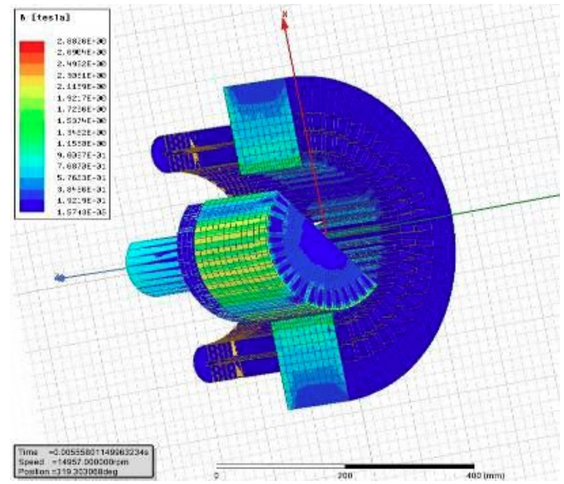
Project Objective(s)

- The primary objective of this project is to develop an integrated motor and drive system for medium voltage, megawatt scale, high speed applications
- Existing electrified high speed systems are not as efficient as they could be and are often comprised of equipment from several different OEMs
- A fully integrated system that utilizes a high speed, medium voltage induction motor and wide band-gap semiconductors integrated into a medium voltage, multi-level drive system is being developed
- The integrated system developed during this project will:
  - Increase overall system efficiency
  - Build upon decades of experience in design and fabrication of induction motors
  - Increase high tech US manufacturing capabilities

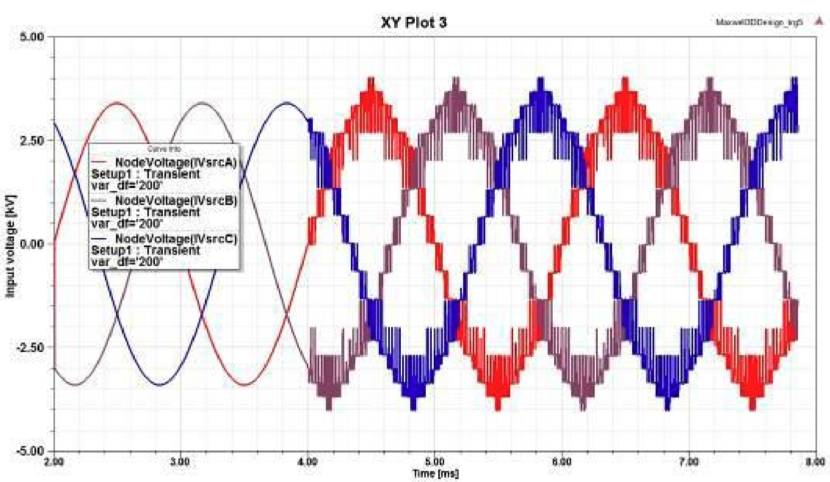
Fully Integrated System Specifications	
VSD Input Voltage	4.16 kV
Targeted WBG devices	Full SiC MOSFET (1700 V)
WBG device switching frequency	5 kHz – 10 kHz
Apparent switching frequency	30 kHz – 60 kHz
Motor fundamental frequency	500 Hz
Motor shaft speed	15,000 rpm
Motor output power	1 MW
Motor output voltage	4,160 V
Overall full load efficiency	> 93%
Overall drive output THD_V (2^{nd} -50^{th})	< 2% without a sine filter
Overall half load efficiency	> 85 %
Input power factor	> 0.99

Technical Innovation

- High speed induction motor
  - Reliable squirrel cage induction motor topology
  - Simplified control: V/Hz and vector control
  - Thin steel laminations with low core loss at high frequency operations
  - Litz wire stator coils to reduce skin effect
  - High speed and high frequency operation produce considerable mechanical and electrical stresses on conventional materials



3D motor models used for design of the high speed induction machine

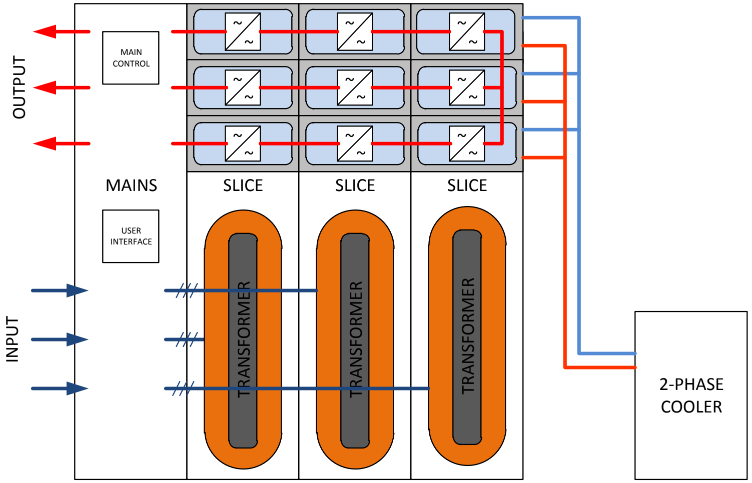


Electromagnetic simulations include drive PWM characteristics to simulate the impacts of dv/dt stress and harmonics

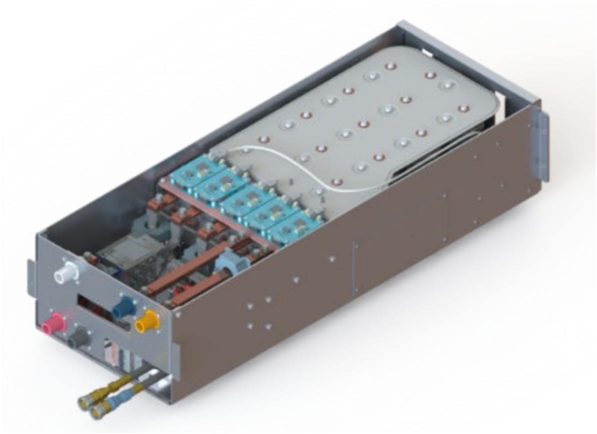
- Electromagnetic, thermal and fluid simulations with finite element analysis
  - Model refinement and validation with benchtop testing of components and materials
  - Utilization of Clemson HPC for 3D motor modeling

Technical Innovation

- High frequency variable speed drive
  - This project builds upon a series connected H-bridge topology that is expandable in both power and voltage levels
  - The multi-level topology presents lower dv/dt stress at medium voltage to simplify motor stator insulation considerations
  - High frequency capabilities of existing Si IGBTs to be significantly increased with SiC MOSFETs (1700V, 400A)
  - System design ready to accept larger current (600A) SiC MOSFETs for a direct 50% power increase
  - Filter-less design for operation with longer cable lengths and less insulation stress



Schematic of the 3 slice SCHB prototype system



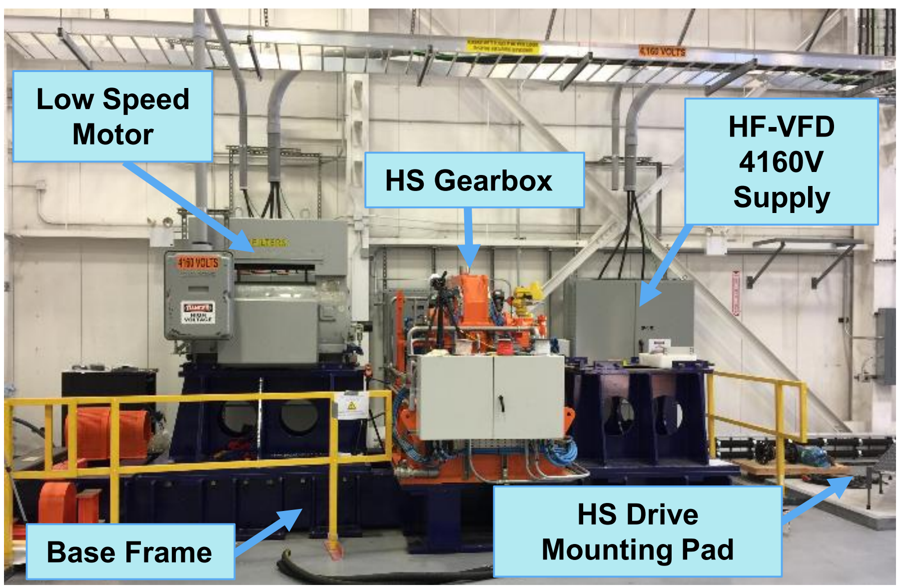
3D model of the power cube converter
(9 power cubes will be used in the prototype)

Technical Approach

- Materials testing, manufacturing process development and model validation are being used to reduce project risks
- Special manufacturing processes have been developed and verified
- Innovative Litz wire modeling techniques are being developed and validated to enable further research

All SiC Power Cube

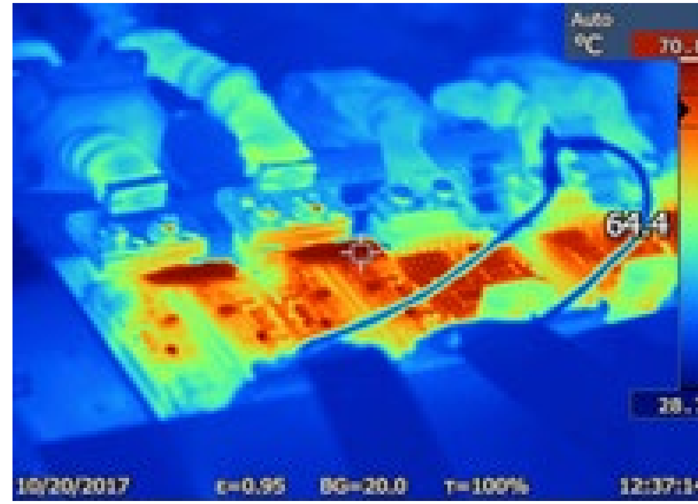
1 MW 15,000 RPM
TECO Motor



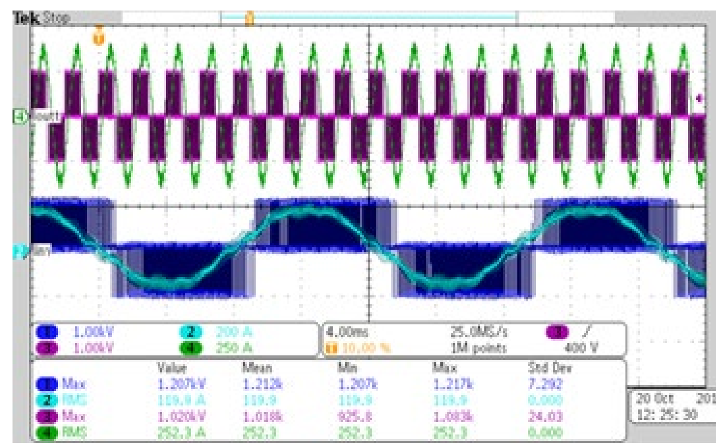
- Extensive test program contains elements for testing the motor, drive and complete system
- Full scale dynamometer testing to be performed at the Clemson University eGRID Center
- Test setup to be used as demonstration platform for potential customers

Technical Approach

- Parallel WBG sourcing approach
  - Hybrid prototype system
    - High frequency SiC output stage
    - Tuned third party SiC gate drive
    - Traditional Si active front end
    - Improved laminated bus work
  - Full SiC prototype slice
    - Both SiC output stages and active front ends
    - Lower cost second source of WBG semiconductors
    - Redesign of laminated DC bus and AC connections
- EMI resistant control hardware design
  - Packetized fiber optic control extended to daughter boards for each gate driver
- Improved internal transformer efficiency



A thermal heat run of a hybrid system converter



Corresponding input and output voltage and current for a 500 Hz 250 A heat run

Results and Accomplishments

- Results to date
  - Motor fabrication and assembly finalized
    - Successfully operated at 15,000 RPM no-load
    - FAT complete with smooth and grooved rotor
    - Packaging and shipment from Round Rock TX to Clemson University underway
  - Variable speed drive fabrication and assembly nearly complete
    - Awaiting final drive components from third party vendor
    - Preliminary drive operation and checkout complete
    - FAT will include operation of the motor at no load
  - Test Plan and Test Execution
    - Completed test plan scope for the prototype system and components
    - All major components have been received for the dynamometer and construction is 75% complete
  - System cost target (1$/W) is easily realizable based upon prototype costs and 500 Units/Year
- Work to be Completed
  - Complete shipment of motor and drive to Clemson
    - June 2019
  - Commission the motor and drive on the dynamometer
    - July 2019
  - Complete the test plan at the Clemson University eGRID Center
    - August 2019 – October 2019

Variable Frequency Drive System FAT setup

High Speed Motor Completed Manufacturing

Transition (beyond DOE assistance)

- In discussions with stakeholders and potential customers
  - Stakeholders include both end users and compressor OEMs
  - Additional high speed motor designs being developed from modeling techniques and materials characterizations
  - Larger range of applications than initially anticipated
- Certification of the system
  - Drive UL listing to build on existing UL certifications
  - Extensive test plan for components and the complete system developed around industry standards
- Development of manufacturing processes and methods
  - Efficient ways to create Litz wire motor stators
  - High strength braising processes for high speed rotors
  - Rotor surface treatments to reduce surface currents