Fully Integrated High Speed Megawatt Class Motor and High-Speed MW Motor for Gas Compression Systems

DE-EE0007254

Clemson University and TECO Westinghouse Motor Co.

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Project Objective

- The primary objective of this project is to develop an integrated motor and drive system for high speed applications
- To increase overall system efficiency, volumetric power density and costs a fully integrated system that utilizes a high speed induction motor and wide band-gap semiconductors is proposed

Fully Integrated System Specifications	
VSD Input Voltage	4.16 – 35 kV set by transformer
Targeted WBG devices	Full SiC MOSFET
WBG device switching frequency	5 kHz – 10 kHz
Apparent switching frequency	30 kHz – 60 kHz
Motor fundamental frequency	500 Hz – 600 Hz
Motor shaft speed	15,000 rpm
Motor output power	1 MW
Overall volumetric power density	< 6.31 m^3/MW
Overall full load efficiency	> 93%
Overall drive output THD_V (2^{nd} -50^{th})	< 2% without a sine filter
Input displacement power factor	> 0.99

Technical Innovation

- Existing electrified high speed systems are not as efficient as they could be and are often comprised of several different OEMs
  - Systems with a high speed gearbox suffer from the additional losses of the gearbox
  - Previous high speed motor applications have utilized de-rated low frequency converters with poor efficiencies at high frequencies
- The integrated system developed during this project will:
  - Increase overall system efficiency removing the gearbox and use a wide bandgap semiconductor high frequency converter
  - Build upon decades of experience in design and fabrication of induction machines to provide a robust and reliable solution
  - Develop US manufacturing of turn-key high speed motor and drive systems for high energy compressor applications

Technical Innovation

- Traditional materials and design methodologies cannot be applied to meet the motor requirements
  - Steel laminations with low core loss at high frequency
  - Litz wire stator coils to reduce eddy currents
  - Rotor dynamics and manufacturing processes to support high rotational stresses
  - Efficient thermal management to enable compact design

- 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

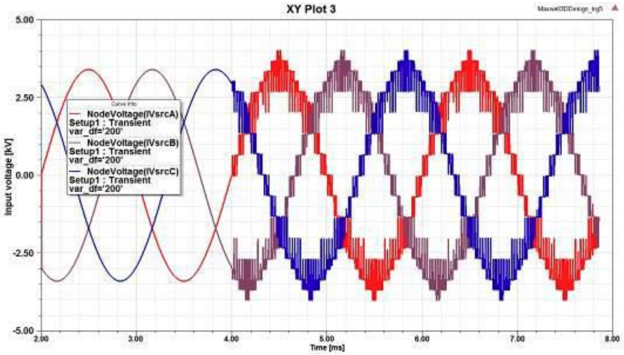
Technical Innovation

- Integration of wide band-gap semiconductors into a modular multi-level drive topology
  - Retrofit a very common half-bridge module (ECONO-Dual package) to aid in short term adoption of wide band-gap semiconductors
  - Power requirements (1700 V, 400 A) stretch the present commercial availability of SiC MOSFET modules
  - Either developments in packaging or gate drivers required to meet protection and performance metrics with today's technology
  - Future redesign of the power modules will be made possible by validating additional MOSFET modules with alternative packaging

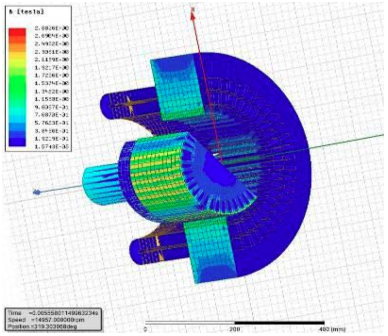
Technical Approach

- 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

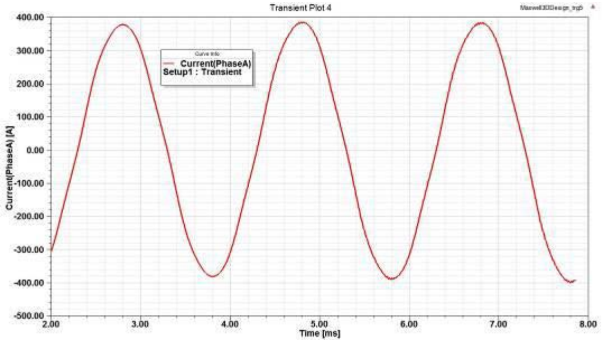
Bench top model validation of a Litz wire coil embedded in a slot



3D FEA Simulated input voltage with PWM



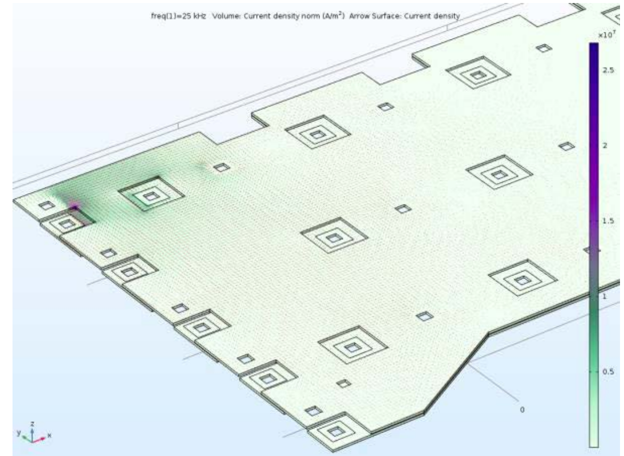
3D FEA Model



3D FEA Simulated Phase A Current

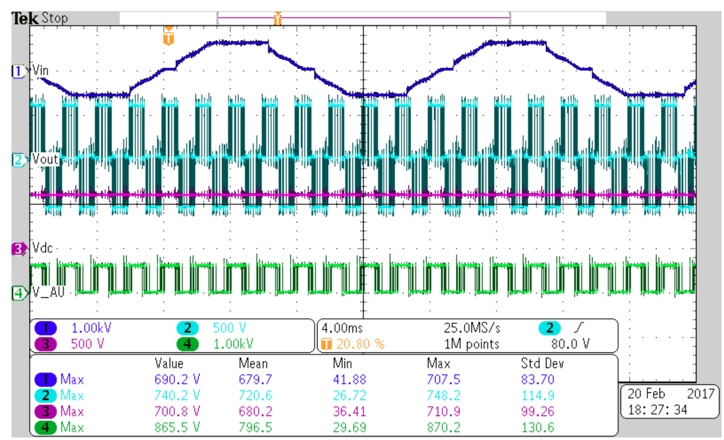
Technical Approach

- Commercially available SiC MOSFET modules did not meet the performance criterion for integration
- Alternative paths have been developed to meet project objectives and ensure competitive pricing in the future
- Improvements to components have increased the efficiency of the system (transformer efficiency up to 98.6%)



DC laminated bus redesigned to reduce inductance by 40%

Benchtop testing setup for a single power module at 164 kVA



Full load SiC-based power cell testing with a single power module

Transition (beyond DOE assistance)

- Contacts with potential stakeholders started in the first quarter of the project
  - Stakeholders include both end users and compressor OEMs
  - Questionnaires communicated with potential stakeholders
  - Power and voltage specifications, performance, reliability and certification requirements, evaluation criterion with respect to cost and efficiency, etc.
- The certification process of the system has begun
  - Request for Field Certification with CSA for the system
  - Drive UL listing to build on existing UL certifications
- Development of manufacturing processes and methods
  - Efficient ways to create Litz wire motor stators
  - High strength braising processes for high speed rotors

Measure of Success

- Electrifying the chemical and petroleum refining industries will greatly increase the efficiency of the two largest energy consuming industries in the USA
- Commercializing a line of high speed motors and high frequency variable speed drives would:
  - Remove the speed increasing gearbox in electrified low speed applications to increase the efficiency by > 1.5 – 2.5%
  - Apply to new applications a direct drive variable speed solution that is 93% efficient to the shaft of the compressor
  - Provide a system that beats a cost target of $1/Watt and increases power density by greater than 200% over the present state of the art

Project Management & Budget

- Project Duration: 30 months
  - May 1st, 2016 – November 30th, 2018
- The project consists of 7 main tasks
  - There is one milestone for each task per quarter
  - Project Go/No-Go points are scheduled on a yearly basis for each task
- The invoicing for the project was delayed but did not impact overall progress
  - Some costs will be shifted to BP2 to account for this

Total Project Budget	
DOE Investment	$ 5,093,046
Cost Share	$ 1,769,942
Project Total	$ 6,862,299

Results and Accomplishments

- Budget Period 1 tasks near completion:
  - The motor design is feasible and will achieve a full load efficiency of greater than 96.5 %
  - SiC MOSFET modules are now able to switch at ~ 8 kV/us with SC protection in ~1.5 us and ~3.6 kA
  - SiC based drive efficiency is calculated greater than 97%
  - Total system efficiency is calculated greater than 93%
- Budget Period 2 tasks include:
  - Manufacturing of the high speed motor and drive
  - Test plan development, including applicable standards
  - Assembly and commissioning of the dynamometer
  - Continuing to engage stakeholders in the R&D process