Medium Voltage Integrated Drive and Motor

Contract Number DE-EE0007251
Calnetix Technologies
May 2016 – April 2019

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U.S. DOE Advanced Manufacturing Office Program Review Meeting
Washington, D.C.
July 17-19, 2018

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Overview

Timeline

- Award issued May 2016
- Projected End date April 2019
- Project 55% complete

Budget

	FY 16 Costs	FY 17 Costs	FY 18 Costs	Total Planned Funding (FY 19-Project End Date)
DOE Funded	$2.369M	$1.271M	$0.345M	$3.986M
Project Cost Share	$0.592M	$0.318M	$0.086M	$0.996M

- Incurred Costs to Date: $3.925M
  - DOE: $3.140M
  - Cost Share: $0.785M

Barriers

- The key barriers are the following:
  - SiC component cost and reliability
  - Medium voltage stator development
  - New magnetic bearing and controls development

Partners

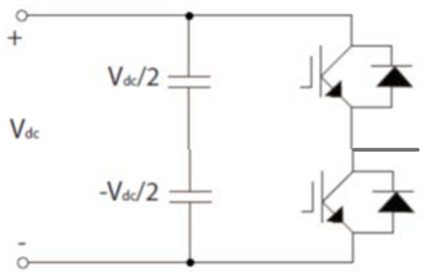
- Wolfspeed (A CREE Company)
  - Developer of next generation SiC modules
- BRG Machinery
  - Magnetic bearing
- Electric Motor & Contracting Company
  - Stator assembly
- Laser Technologies
  - Laminations and stacking

Project Objective

- Project Goal
  - Develop a medium voltage direct drive and permanent magnet synchronous machine using next generation Silicon Carbide modules
- Benefits
  - Higher efficiency
  - Smaller footprint
  - Eliminates gearbox and associated auxiliaries
  - Supports innovative technology into commercialization
- Applications
  - Oil & Gas industry for gas compression
  - Expander for power generation (waste energy recovery)
- Issues Addressed
  - Current technology is dated using turbine/engine driven topology or induction motor with gear drive train
  - Poor operating life (unmanned site) and maintenance
  - Poor load response, low efficiency and environmentally unfriendly
- Challenges and Difficulties
  - Developing high efficiency small size bi-directional inverter using state of the art high efficiency wide band gap devices having extremely high switching speeds
  - Stator and Rotor construction to meet the high speed operation with long operating life
  - Managing circulating bearing currents due to high switching frequency of VSD inverter

Technical Innovation

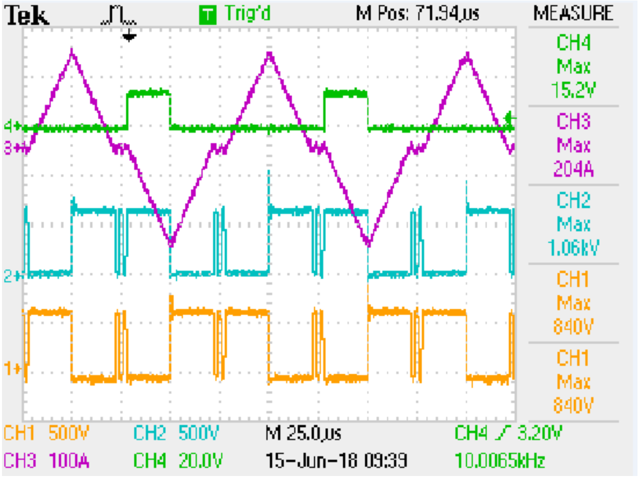
- Existing technology limitations
  - Early generation - turbine or engine driven compressors
  - Second generation – Low speed (3.6 krpm) induction motors with gear train to increase speed
  - Fixed speed, large footprint, low operating life and efficiency, auxiliaries required, and high maintenance
- New approach
  - Two level inverter utilizing 10 KV Silicon Carbide (SiC) modules
  - Allows fast acceleration and deceleration, simple controls, fewer parts, and modular
  - Permanent Magnet Synchronous Motor (PMSM)
    - High efficiency, small size
  - Magnetic Bearing
    - Maintenance free operation, minimizes auxiliaries
  - Motor
    - Incorporating best commercially available insulation system
    - Integrating dv/dt filter to smoothen the high switching transients of two level SiC device



- Development of variable speed drive and permanent magnet synchronous motor will increase overall efficiency, reduce footprint, and reduce required maintenance costs

Technical Approach

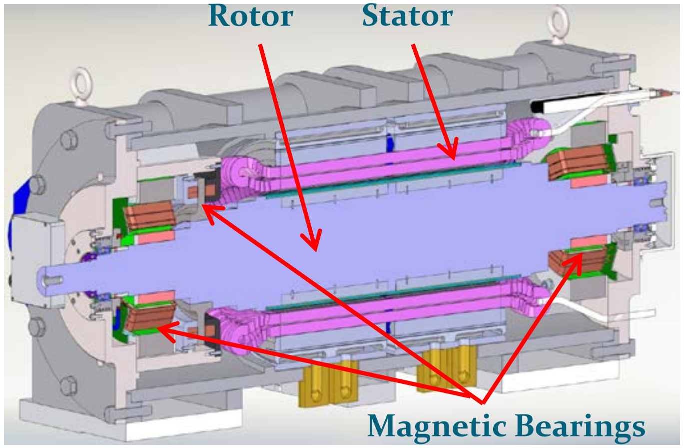
- VSD Design
  - Validate existing Calnetix sensorless variable speed drive controller in a high dv/dt environment - Complete
  - Develop a half-bridge medium voltage two level switching inverter - Complete
  - Small footprint inverter design - Complete
  - Test 10 kV SiC devices - Ongoing
    - High voltage static test – no switching
    - Low voltage with highest possible current switching test (200A peak)
- Partners:
  - Cree/Wolfspeed for 10KV dual SiC module and high speed gate driver board
  - CTM magnetics for medium voltage L-C filter
- Risks and Unknowns
  - 10 kV SiC device is relatively new
  - Cost model is high today
  - Impact of high dv/dt not fully understood



Ch4: Gate Drive Voltage (20V/div)
Ch3: Load Current (100A/div)
Ch2: High Side Vds (500V/div)
Ch1: Low Side Vds (500V/div)

Technical Approach

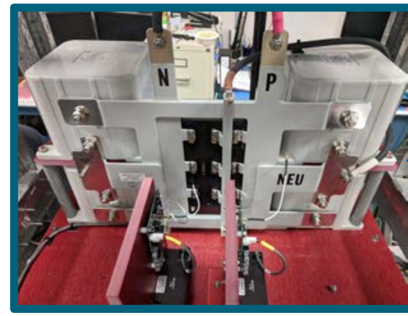
- 1.6 MW Machine
  - High speed medium voltage (4,160 VAC)
  - Permanent magnet synchronous machine
  - Magnetic bearing levitation
- Partners
  - BRG Machinery – Magnetic bearing
  - Electric Motor & Contracting Company – Stator assembly
  - Laser Technologies – Laminations and stacking
  - KenCoil – Stator coil forming
- Risks and Unknowns
  - Stator cooling with MV insulation system
  - Mitigation of dv/dt
  - Circulating bearing currents
- Execution Attributes
  - Calnetix has had multiple successes in launching product lines and companies using core technologies consisting of permanent magnet synchronous machines, magnetic bearings, and associated controls

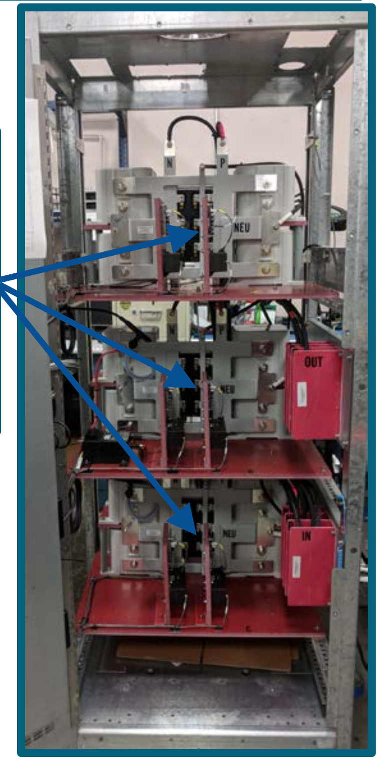


1.6 MW Machine Layout

Results and Accomplishments

- Results to Date
  - Software Controls (1.2 kV SiC) – validated Calnetix controls compatible with SiC devices
  - Half-Bridge Module Inverter Cabinet testing completed
  - Power Electronics Inverter Cabinet
    - Completed cabinet design
    - Manufacturing in process
  - Machine design
    - In manufacturing
      - Stator, rotor, actuators
    - Detail Design – Final stages
      - Housing, endbells, stator cooling jacket, magnetic bearing controller
  - Volumetric Analysis
    - VSD on track
    - Motor footprint close to FOA target
- Work to be Completed
  - Finalize 1.6 MW machine design and manufacture
  - VSD
    - Finish manufacturing of VSD
    - Conduct low voltage testing (750VDC)
    - Inductive load test
    - Spin test
  - Motor
    - Finalize 1.6 MW machine design and manufacture
    - Finish stator and rotor assembly
    - Complete magnetic bearing actuators
    - Final build and spin test





Estimated Volumetric Performance Metrics

Components	Parameters	FOA Goal	Existing Technology	Projected
VSD	Footprint (m^2/MW)	0.791	1.645	0.79
	Inverse Vol. Density (m^3/MW)	1.515	4.545	1.51
Motor	Footprint (m^2/MW)	0.625	2.5	0.496
	Inverse Vol. Density (m^3/MW)	0.25	2.0	0.309*

* - Was: 0.172 m^3/MW; increased due to structural housing modes

Transition (beyond DOE assistance)

- Industry Drivers
  - Industry is strongly on the lookout for electric direct drives for compressors, pressure let down expanders, large gas turbine generators
  - Both pipeline owners and direct operators desire better efficiencies and lower operating costs (reliability/ lower down time/ fewer auxiliaries)
- Business Model and Value
  - Calnetix's business model is to directly work with Original Equipment Manufacturers (OEM)
  - Typical OEM's
    - Compressor/turbine manufacturers
  - Typical Applications
    - Pipeline owners, gas gathering entities, terminal owners
  - Benefits
    - Land based applications: Higher availability and lower operating costs
      - Less maintenance, less equipment, lower down time
    - Offshore applications: Higher capacity and smaller footprint/volume
      - Increased service intervals and less equipment

Transition (beyond DOE assistance)

- Commercialization Approach
  - Work with a medium/ large compressor OEM or end user to apply in compression for beta testing
  - Concept demonstration to the industry followed by a dedicated product development for actual power and speed for a family of existing compressor trains
- Technology Sustainment Model
  - Reinvestment in the developed technology by expanding the technology to the whole family of Calnetix drives and motors
  - Partnering with early adopter customers to apply the technology in other areas of merit and interest

Questions?