Medium Voltage Integrated Drive and Motor

Contract Number DE-EE0007251
Calnetix Technologies
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Pana Shenoy, Calnetix Technologies, Principal Investigator
Octavio Solis, Calnetix Technologies, Presenter

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Overview

Project Title: Medium Voltage Integrated Drive and Motor

Timeline:

Project Start Date: 05/01/2016

Budget Period End Date: 08/31/2019

Project End Date: 02/29/2020

Project Budget and Costs:

Budget	DOE Share	Cost Share	Total	Cost Share %
Overall Budget	$4,835,609	$1,208,902	$6,044,511	20%
Approved Budget (BP-1&2)	$4,504,253	$1,126,063	$5,630,316	20%
Costs as of 4/30/19	$3,869,664	$967,416	$4,837,080	20%

Barriers and Challenges:

- SiC component cost and reliability
- Medium voltage stator development
- New magnetic bearing and controls development

Project Team and Roles:

- Wolfspeed (A CREE company)
    - Developer of next generation SiC modules
- BRG Machinery
    - Magnetic bearing
- CTM
    - Motor inverter filter inductors

AMO MYPP Connection:

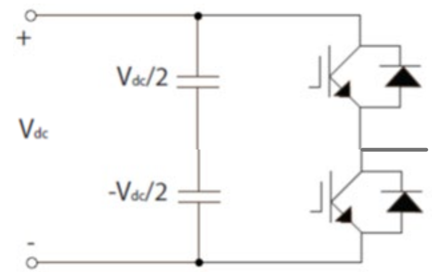
- Wide Bandgap
    - Semiconductors for Power Electronics
- Advanced Sensors, Controls utilizing magnetic bearings
- Waste Heat Recovery Systems
    - Commercialization plan is to modify existing product platform to increase energy density

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

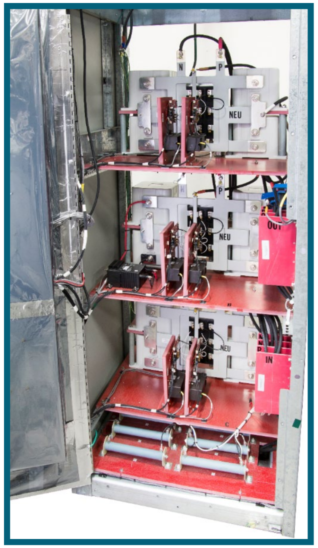
- Existing technology limitations
  - Early generation - turbine or engine driven compressors
  - Second generation – Low speed (3.6 krpm) induction motors with gear train to increase speed
  - Fixed speed, large footprint, low operating life and efficiency, auxiliaries required, and high maintenance
- 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
  - Three-phase inverter development
    - Design - Complete
    - Testing/validation - Ongoing
- 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



1 MW 3 Phase SiC Drive

Technical Approach

- 1.6 MW Machine
  - High speed medium voltage (4,160 VAC)
  - Permanent magnet synchronous machine
  - Magnetic bearing levitation

1.6 MW Rotor

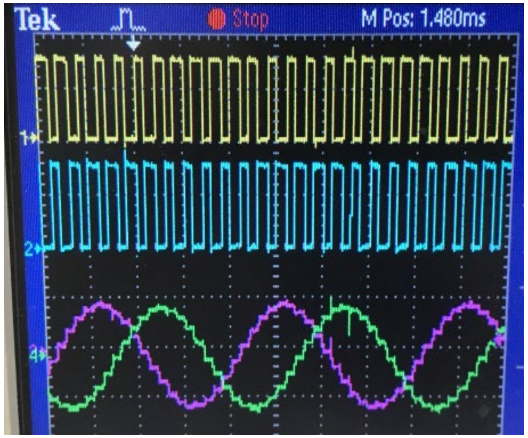
- Partners
  - BRG Machinery – Magnetic bearing
  - Electric Motor & Contracting Company – Stator assembly
  - Laser Technologies – Laminations and stacking
  - KenCoil – Stator coil forming

1.6 MW Stator

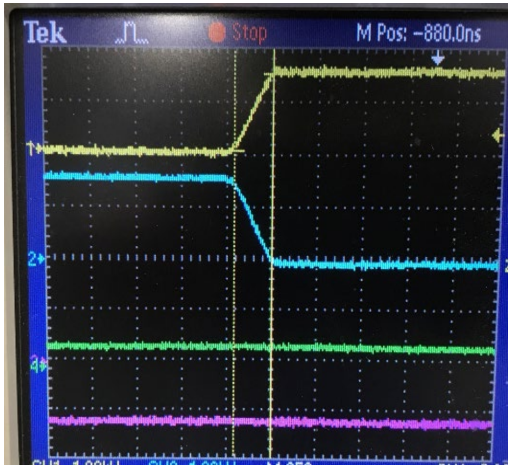
- Risks and Unknowns
  - Stator cooling with MV insulation system
  - Mitigation of dv/dt
  - Circulating bearing currents
- Execution Attributes
  - Calnetix has had multiple successes in launching product lines and companies using core technologies consisting of permanent magnet synchronous machines, magnetic bearings, and associated controls

Results and Accomplishments

- Results to Date
  - VSD
    - Completed packaging of three phase drive system
    - Motor controller tuned for Three phase PM machine operation
      - Developed new parameter file to spin a PM machine
      - Spun low voltage machine to 10 krpm to validate stable operation (**demonstrated to DOE**)
    - Operated Inverter in a passive load condition of 100 Amps peak at 4,500 Volt DC bus voltage
  - Technical challenges:
    - One device failure at 4,500 Volts operation
    - Device manufacturer has evaluated the failed device, recommended to use next generation device
    - Lead time for next generation SiC devices
  - Next steps:
    - Increase DC bus voltage to 6,300 Volts to yield 4,160 Volts at inverter output terminals
    - Spin the motor to rated speed 15 krpm
    - Passive loading of the inverter to 140 Amps



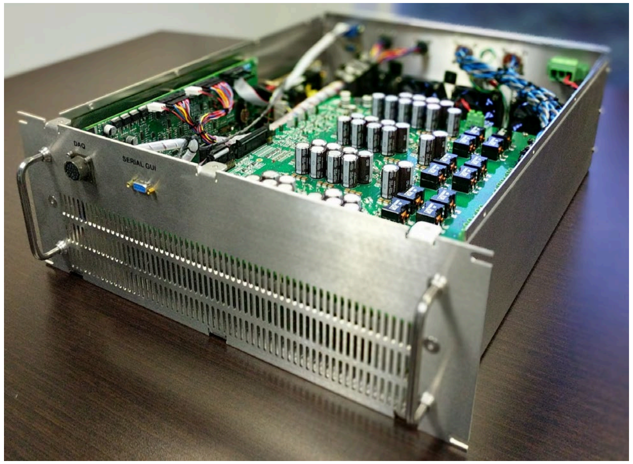
- Switching Voltage @ 4500 Volts DC bus
- 5 KHz PWM frequency
- Load: 100 Amp peak; 500 Hz fundamental frequency



- Switching Time: 220 n sec
- Switching DV/DT = 4500V/220 n sec = 21 KV/u Sec

Results and Accomplishments

- Results to Date
  - Motor
    - Design - Complete
    - Magnetic Bearing Controller - Complete
    - Stator assembly manufacturing – Complete
    - Rotor assembly manufacturing – In process
    - Machined components – In process
  - Technical challenges:
    - dV/dt effects on machine
      - Expecting ~21kV/usec
      - dV/dt filter designed to mitigate dV/dt effects
    - Verification of magnetic bearing operations and controls
    - Verification of cooling scheme to analytical results
  - Next Steps:
    - Finish manufacture and build of machine
    - Low speed spin testing for machine
    - Validate magnetic bearing controls
    - Validate cooling scheme



Magnetic Bearing Controller
MBC 9600

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

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