Integrated Electric Drive with HV^2 Modular Electric Machine and SiC Based Power Converters

DE-EE00007255

The Ohio State University/National Renewable Energy Laboratory

Jan. 2016 to Dec. 2018

PI: Prof. Longya Xu, The Ohio State University

Presenter: Prof. Julia Zhang, The Ohio State University

U.S. DOE Advanced Manufacturing Office Program Review Meeting

Washington, D.C.

June 11, 2019

Overview

Timeline

- Award issued Jan. 2016
- Projected End date Dec. 2019
- Project 100% complete

Budget

	FY 16 Costs	FY 17 Costs	FY 18 Costs	Total Planned Funding (FY 19-Project End Date)
DOE Funded	545 K	811 K	614 K	2.1 M
Project Cost Share	250 K	212 K	213 K	700 K

Barriers

- High power density, efficiency, voltage.
- Very wide operation frequency range.
- Complex control.
- Potential strong EMI.
- Low frequency control.
- High insulation requirement.

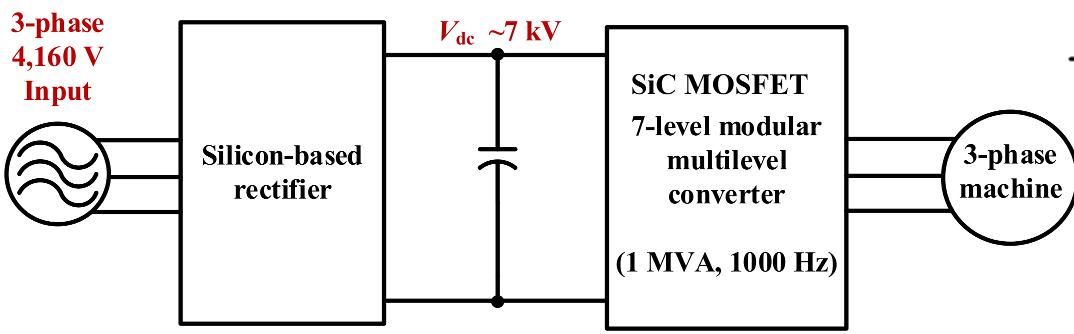
Partners

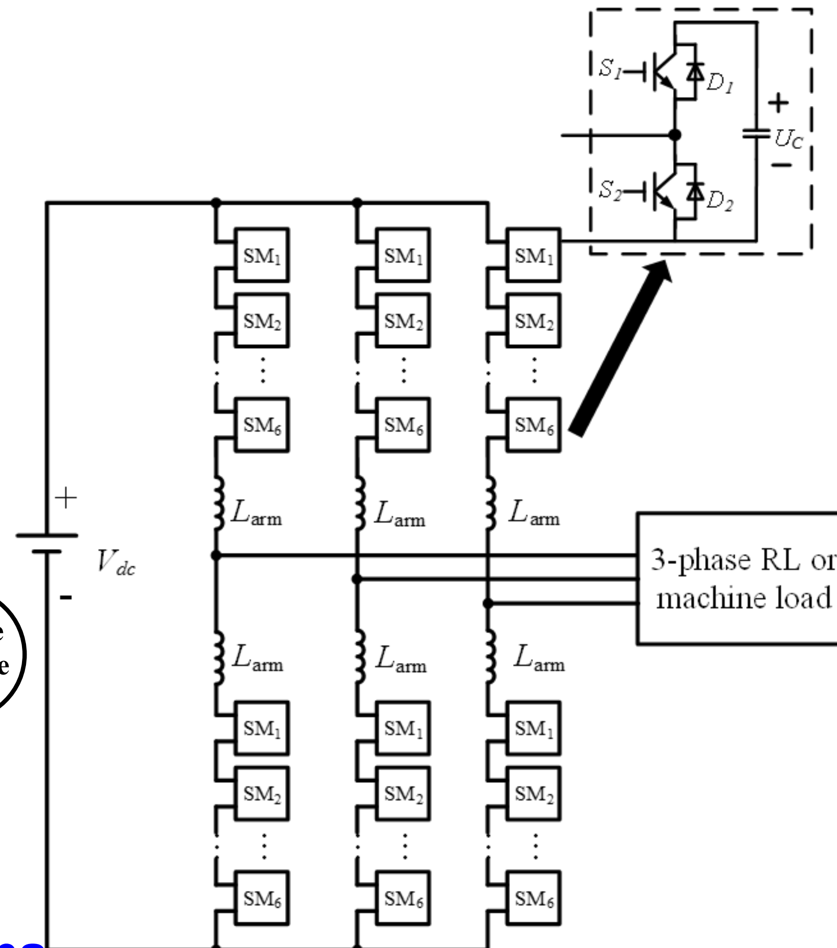
- The Ohio State University: design, build, and test the MMC converter, integrate with a motor.
- Oregon State University: controller hardware and software design.
- National Renewable Energy Lab: power converter thermal analysis and packaging design.

AMO MYPP Connection: Wide bandgap semiconductors for Power Electronics. More economically viable, energy efficiency improvement, cost-efficient, accelerate adoption of clean energy.

Project Objective

- Design, build, and test a high voltage, high speed SiC-based variable frequency drive (VFD).
- Performance targets: power density>0.66 MW/m^3, efficiency 99% @1 MW/1 kHz.
- Major challenges:
  - Potential strong EMI
  - High number of sub-modules
  - High voltage insulation problems
  - Low speed control





Pilot project on transformer-less high voltage high speed machine drive systems

Technical Innovation: State-of-the-art

❑ Pros and cons of current practice and this project

3-level Neutral Point Clamped Voltage Source Inverter (3L NPC VSI)

•**Pros: least devices, low switching frequency**

•**Cons: unequal semiconductor-loss distribution**

•**Product price:** $186,000 (e.g., ABB ACS 1000, SIEMENS GM150/SM150)

9-Level Cascaded H-Bridge Voltage Source Inverter (9L HB VSI)

•**Pros: high drive power**

•**Cons: bulky and complicated zigzag transformer**

•**Product price:** $158,766 (e.g., Allen-Bradley PowerFlex 6000)

4-Level Flying Capacitor Voltage Source Inverter (4L FC VSI)

•**Pros: high bandwidth**

•**Cons: bulky and complicated zigzag transformer**

•**No information about product price** (e.g., Alstom ALSPA VDM6000)

This project: 7-Level Modular Multi-Level Converter Voltage Source Inverter (7L MMC VSI)

•**Pros: high speed, high efficiency, upgradable to transformer-less with high voltage devices**

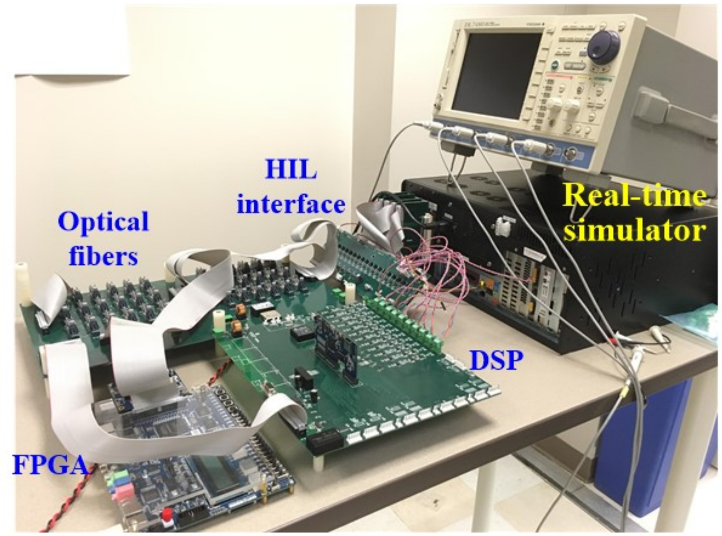
•**Cons: large number of sub-modules**

•**Estimated cost:** $60,000 (competitive, especially if wide bandgap device price is reduced, 50% of the total now)

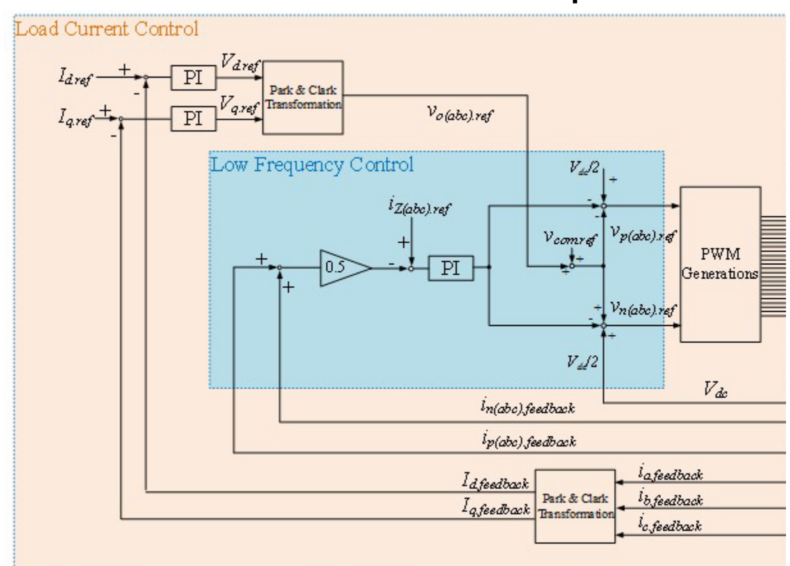
Technical Innovation: Innovations

Challenges	Innovative Solutions
High power: 1 MW, High voltage: 7-kV, High frequency: 1 kHz	Pilot project on transformer-less electric machine drives, SiC MOSFETs, modularized design methodology
Complex control algorithms with limited calculation time	DSP+FPGA structure
Potential strong Electromagnetic Interferences (EMI)	Fiber-optic signal transmission/improved layout design/multi-stage isolated auxiliary power supplies
PWM, fault signals and sensing signals from 36 modules	Modular control-card designs, multi-tier gate drives design
Low frequency control of MMC Drive	Improved low frequency control algorithms
High insulation requirement	Partial discharge monitoring and measurement

Hardware innovation example



Software innovation example



Technical Approach:

❑ Scientific/technological approach

- Define system requirements: performance and cost targets
- Evaluate hardware components: simulations and tests
- Submodule integration and function validation: hardware-in-the-loop and experimental tests.
- Machine and drive system integration: hardware-in-the-loop and experimental tests.
- System tests: across full voltage, current, and frequency ranges.

❑ Participants and responsibilities

- **The Ohio State University:** device characterization, design and build gate drive circuits and main circuits of SiC, control algorithm development, system integration, hardware-in-the-loop tests, experimental tests on a rotating dynamometer
- **Oregon State University:** design of controller and peripheral circuits, sensor selection and conditioning circuit design, control algorithm development and experimental verification.
- **National Renewable Energy Lab:** thermal analysis and packaging design

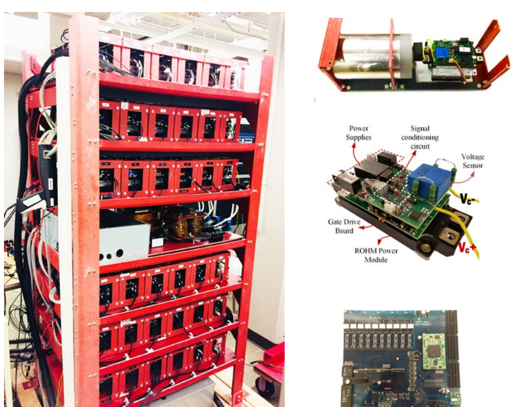
Results and Accomplishments

❑ Milestones and Accomplishments

- Built and tested a 3-phase 1-MVA 7-kV 7-level MMC. Tested across its full voltage/current/freq range using an RL load.
- Used the MMC to drive 1 permanent magnet synchronous machine to run at 15000 rpm (1 kHz), full current, reduced voltage.
- Thermal working cycle test under rated voltage, current, and frequency.
- Acoustic noise measurement: 77 dB under full voltage and current. Sensor 3 m away.
- Computation and analysis of harmonic distortion for MMC.

❑ Achievement Metrics

- Efficiency: target 8-kW loss at 1 MW (99.2%), achieved 4.1-kW losses at 1 MVA.
- Power density: target >0.67 MW/m^3, achieved 0.83 MW/m^3



3-phase MMC tower


Motor dyno tests


Live demo to industry

Transition

- **Barriers to Adoption**
  - Large cost reduction of the proposed system
  - Replace old equipment and installation of new systems
  - Highly-qualified engineers with comprehensive knowledge of VFD and WBG devices
- **Commercialization Plan**
  - **Technology documentation and dissemination (throughout this project):** publishing papers and reports, invite key industry members in the field to workshops and seminars.
  - **Reach out to commercialization partners (year 3):**
    - *Tier 1 manufacturers:* U.S. oil and natural gas equipment manufacturers such as Caterpillar and GE Oil and Gas.
    - *Tier 2 manufacturers:* U.S. electrical equipment manufacturers such as Emerson Network Power, GE Aviation, Rockwell Automation.
    - *Tier 3 manufacturers:* Foreign electrical equipment manufacturers operating globally including ABB, Siemens, Toshiba, and Alstom
    - *System integrators and operators:* oil and gas producers, renewable integrators, and utility companies to seek field demonstration opportunities.
  - **Team has identified the commercialization partner: Toshiba USA.**
  - **Two follow-up DoE awards (through PowerAmerica Program) to commercialize the developed MMC technology in this DoE project. Budget Period 4: started in 07/2018 and lasts for 1 year. Budget Period 5: starts 08/2019 and lasts for 1 year.**