Integrated Electric Drive with HV2 Modular Electric Machine and SiC Based Power Converters

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The Ohio State University/National Renewable Energy Laboratory

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Overview

Timeline

- Award issued Jan. 2016
- Projected End date Dec. 2018
- Project 90% 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

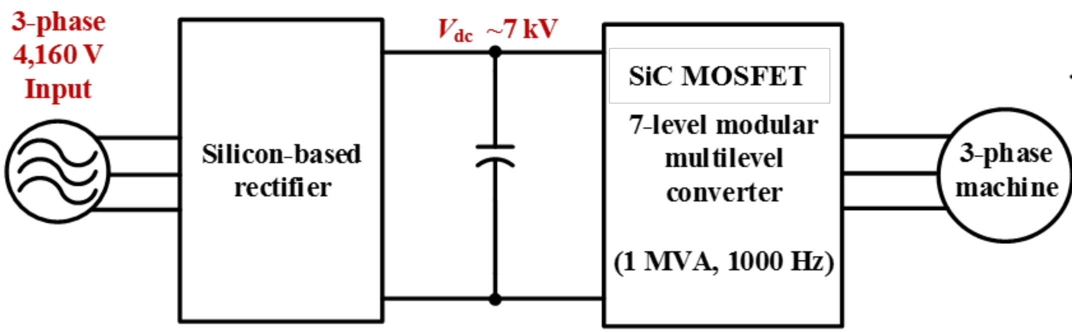
- High power density, efficiency, voltage.
- Very wide operation frequency range.
- Complex control.
- Potential strong EMI.
- Low frequency control.
- High insulation requirement.

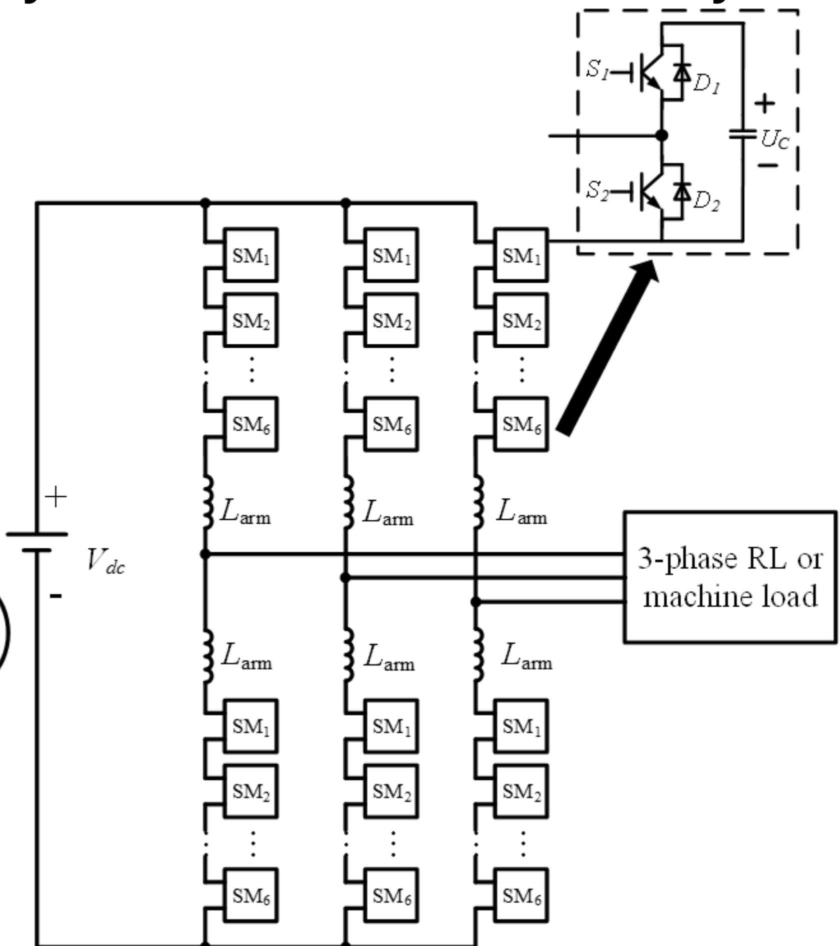
Partners

- 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.

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)

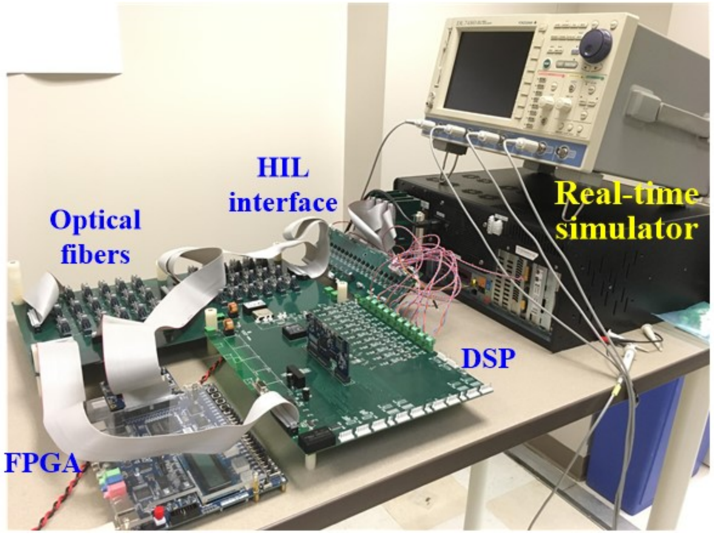
This project: 7-Level Modular Multi-Level Converter Voltage Source Inverter (7L MMC VSI)

- **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)

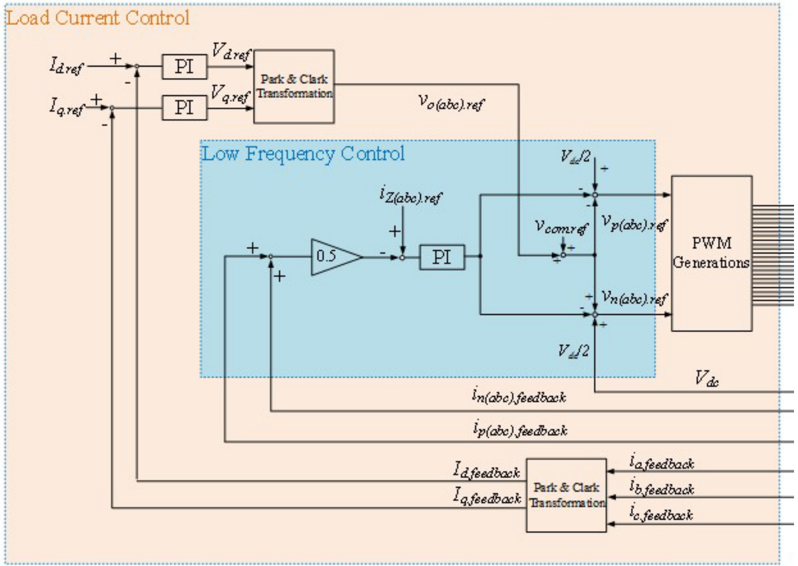
Technical Innovation: Innovations

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

Technical Approach:

Potential project risks and unknowns	Mitigation method and timeline
The drive efficiency might not meet the target	Device selection and test, individual device and converter sub-module tests. Quarter II & III of Year 1
Costs of the drive system might not be competitive compared to existing technology	Reduce design margin, work with multiple component manufacturers to understand the tradeoff between cost and performance. Quarter I, II, & II of Year 1
Pre-mature insulation failure caused by fast switching transients and reflected waves.	Partial discharge monitoring and measurement. Quarter II of Year 2 to the end of project
Cannot find a 1-kHz 1 MVA machine for tests	Test current, voltage, frequency capabilities separately using 3 electric machines. Year 3 of the project

Results and Accomplishments

❑ Milestones and Accomplishments since June 2017

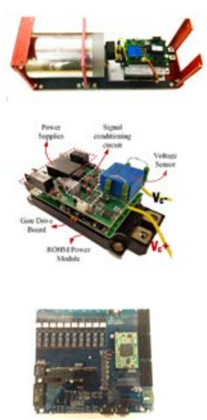
- Built and tested three phase legs under rated voltage/current/frequency using an RL load.
- Integrated the three-phase MMC with a 15000-rpm permanent magnet synchronous machine.
- Used the MMC to drive the machine to run at 15000 rpm (1 kHz), full current, reduced voltage.

❑ 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

❑ Ongoing work

- Preparing for DoE onsite demonstration.
- Testing the MMC with an induction machine.
- Tests on MMC interfacing with the power grid.



3-phase MMC tower

Motor dyno tests

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):**
    - <u>*Tier 1 manufacturers:*</u> U.S. oil and natural gas equipment manufacturers such as Caterpillar and GE Oil and Gas.
    - <u>*Tier 2 manufacturers:*</u> U.S. electrical equipment manufacturers such as Emerson Network Power, GE Aviation, Rockwell Automation.
    - <u>*Tier 3 manufacturers:*</u> Foreign electrical equipment manufacturers operating gloabally including ABB, Siemens, Toshiba, and Alstom
    - <u>*System integrators and operators:*</u> oil and gas producers, renewable integrators, and utility companies to seek field demonstration opportunities.
  - ✓ **Team has identified the commercialization partner: Toshiba USA. A follow-up DoE award to commercialize the developed MMC technology in this DoE project. Starting from July 2018.**

Questions?