Resistively Graded Insulation System for Next-Generation Converter-Fed Motors

DE-EE0007873

GE Global Research

06/2017 – 07/2018

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

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Overview

- One year project w/ no-cost extension (06/2017 – 07/2018)

Project quarter	Task & Milestone
✓ Q1	• Component material properties selected based on analytic model
✓ Q2	• Multi-physics model validated • Preliminary formulations for resistive material selected • Film vendor selected
✓ Q3	• Final materials system selected • Materials produced for endurance test • Endurance test protocol determined
Q4+	• Voltage endurance test completed

Status: Project completion by review date

	FY 17 Costs	FY 18 Costs	Total Funded
DOE Funded	$509K	$238K	$749, 990
Cost Share	$128K	$59K	$187, 497
Project Total	--	--	$937, 487

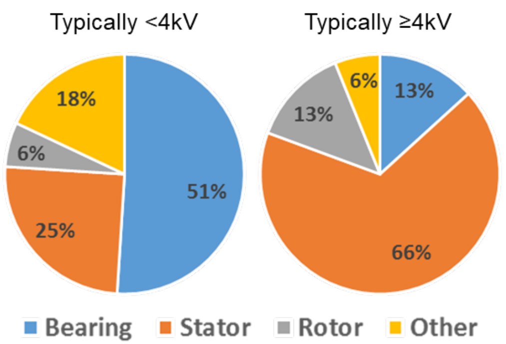
Key challenge:

High frequency, fast rise time/overshoot lead to increased insulation stresses in converter fed motors

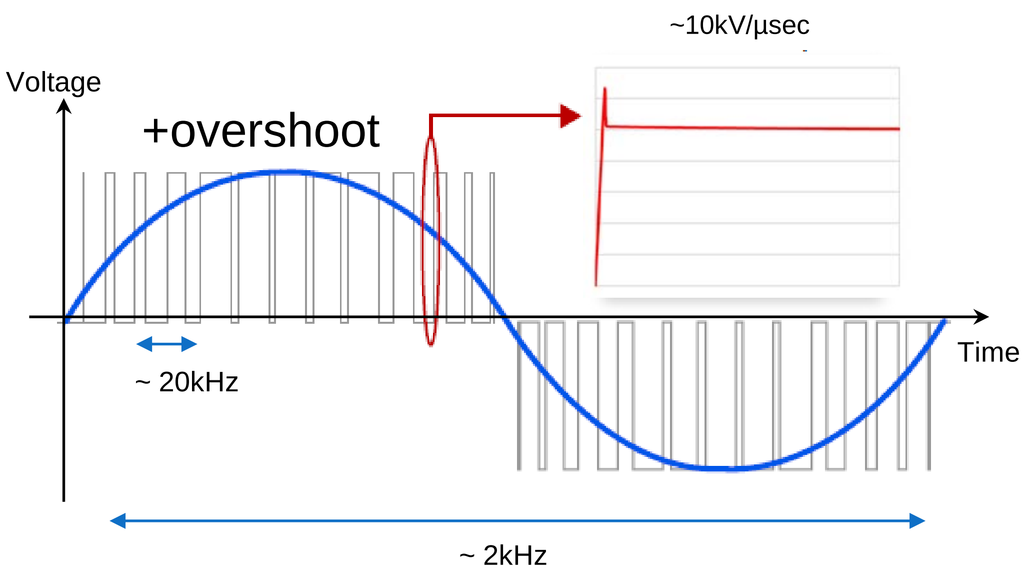
Project Objective

- Achieve 2x operating electric field compared to the state-of-the-art insulation for converter-fed machines to enable 5 – 10 % energy savings with silicon carbide drives
- Key challenges targeted in this program: high frequency, high dV/dt + overshoot enhanced insulation degradation

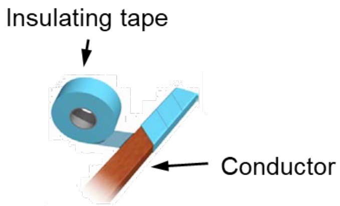
Motor failure modes

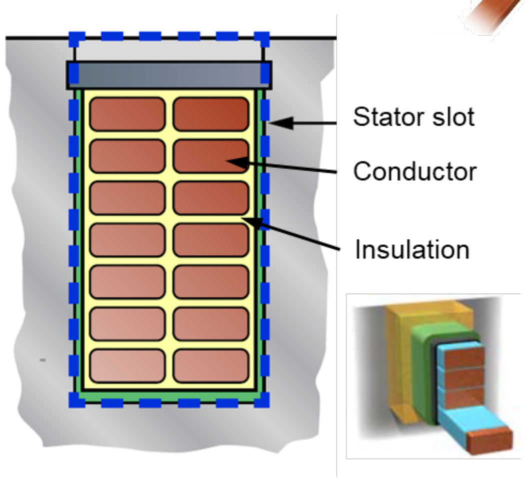


Waveform (drives with silicon carbide devices)



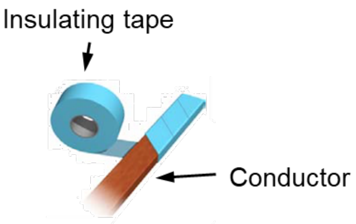
Stator slot structure

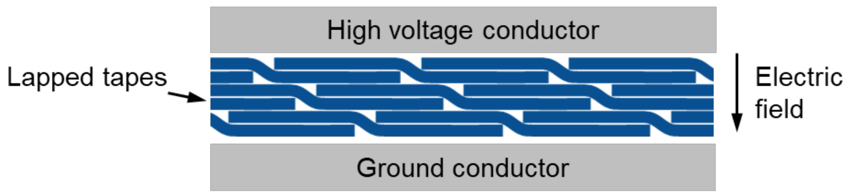


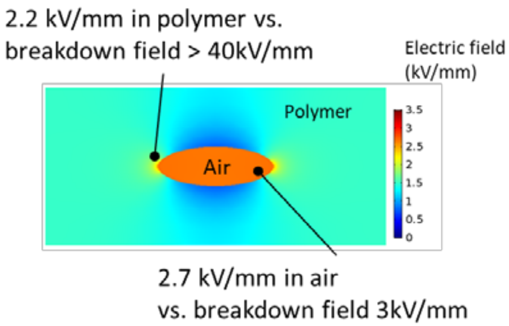


Technical Innovation

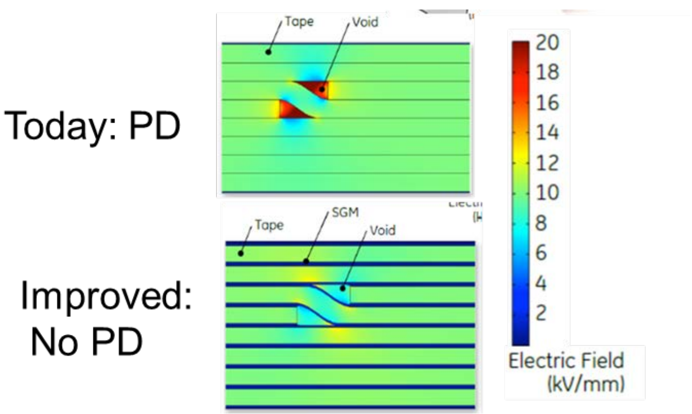
- Insulation application by taping of conductors leads to void defects.
- Air in voids breaks down with applied voltage (partial discharge, PD) leading to insulation degradation.
- State of the art approach uses inorganic (mica) to protect organic insulation from degradation.





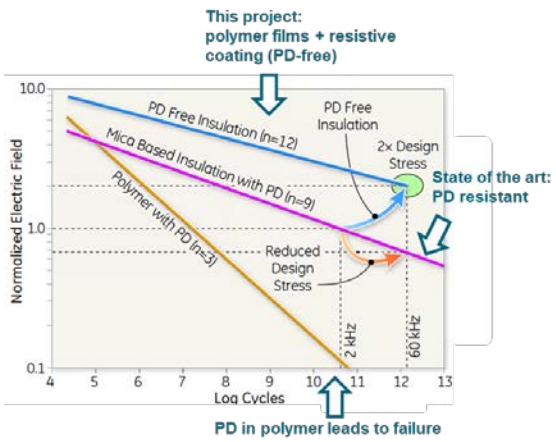


- Innovation: Prevent the degradation mechanism (PD) from occurring by applying appropriate coating and utilize high dielectric strength films to sustain higher electric field. Insulation can be applied to conductor using current process (taping).



Technical Innovation

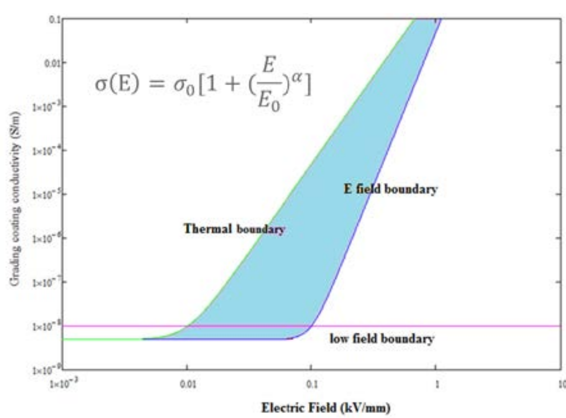
Design entitlement

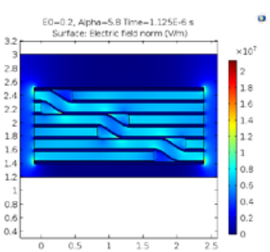


- High frequency and voltage overshoot reduces insulation life.
- Removing partial discharge as a degradation mechanism can allow higher operating stresses while maintaining insulation life.
- High dielectric strength films support higher electrical stresses.
- No insulation overbuild is necessary.

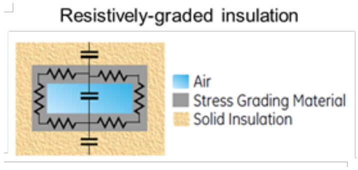
Nonlinear material and structure integration

- High conductivity is required locally to prevent breakdown in voids.
- Low conductivity is required to maintain insulation integrity and low loss.
- Nonlinear conductive materials (SiC powder based) allow balance of insulating properties (global) and conducting properties (local) based on field distribution. Proper selection of nonlinear electrical properties is critical.



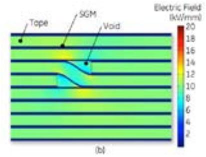


Resistively-graded insulation



Technical Approach

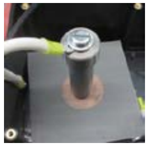
1. <u>Multi-physics modeling</u>
- Analytical model for initial feasibility
- Model insulation structure for electric field and temperature distribution
- Integrate model with test results
- Provide guidelines for material parameters based on waveform and insulation structure



<u>2. Materials formulation and experimental validation</u>
- Insulation film and binder selection based on compatibility and temperature requirements
- Screen nonlinear stress grading materials
- Perform lab testing on panels mimicking insulation structure

<u>3. Process scale-up</u>
- Select material candidates based on modeling and experiment
- Scale process to continuous coating
    - Enable desired structure and quantity for additional insulation testing
    - Proof of concept for scalability

<u>4. Validation tests</u>
- Materials/structure characterization from scaled up process
- Voltage endurance for life estimate



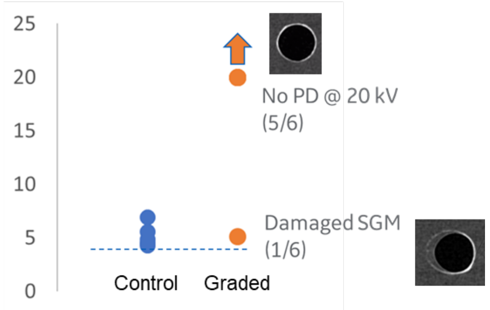
<u>Key challenges:</u>
- Shielding vs. loss tradeoff (material selection)
- Geometry of voids & resistive network
- Time required to measure the effectiveness
- Process control

Results and Accomplishments

- **Accomplishments:** Completed Milestones 1-5
  - Analytical model developed for quick design guidance on structure/material properties. Used for initial selection of resistivity and layer thickness for experiment targets and multiphysics model.
  - Multiphysics model developed and validated critical parameters (no partial discharge, temperature rise within accepted design guidelines). Electric field and temperature distribution consistent with 30 year life based on film property entitlement. Model and outputs can be used for future design implementations.
  - Screened coating materials (8 candidates) for conductivity vs electric field including concentration effects. Screened and selected binder/film materials based on compatibility. Film/binder temperature rating up to 170 C.
  - Model + experimental results used to select insulation structure + materials that can be discharge free with overlap defects. Targeted for 3 kV/mm operation at 20 kHz switching and 10 kV/μs rise time.
  - Scale-up feasibility shown and materials produced on production scale equipment (200 ft roll, 10 inch wide). Sufficient for >50 panels.
  - Test panels designed to estimate life for 3 kV/mm operating field. Designed for no surface discharge on insulation.

- **Work to be completed before AMO review**
  - Voltage endurance experiment on panels (Milestone 6). 60 Hz and square wave testing.

- **Required future work**
  - Improved production process for life testing.
  - Testing on conductors.
  - Integration into machine.



Transition (beyond DOE assistance)

- Process optimization and application to conductors → ongoing
- Targeted product - high performance rotating electric machines
- MV/HV industrial motors – large market; traditionally conservative towards new technologies; conscious of capital expense cost increases
- Overcome barriers to market transition through relevant applications:
  - Aviation (electric propulsion, starter/generator)
  - Transportation (locomotive traction motor)
  - Oil and gas (electric submersible pumps)
  - Power (turbo-generators)

Questions?