U.S. DEPARTMENT OF
ENERGY
Office of Electricity

Robust Insulation for Resilient Transformers and Power Electronics

TRAC Program Review

US Department of Energy, Office of Electricity

Presented at Oak Ridge National Laboratory

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Project Overview

- High temp and high frequency nano-fiber composite insulation for improved grid component and power electronic resilience
  - Blend thermal and dielectric properties of glass with the mechanical properties of paper
  - Leverage LDRD high temp insulating composites, quantify and incorporate high frequency durability
- 500K DOE-OE award (Sep 2019 -> April 2021) will leverage ~1.5M LDRD
- Project lead: INL
- Partners:

Dr. Terry Ring (University of Utah) – Advisor to identifying high temperature tolerant materials
Center of Advanced Energy Studies (CAES) – Leverage material characterization equipment
Boise State University – Material characterization

Background

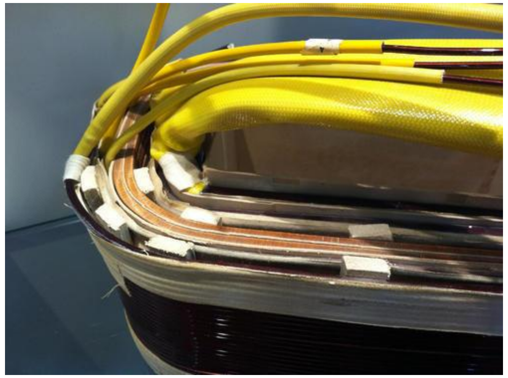
- EHV Transformers are long lead time, high cost, limited spares replacement items

- Foreign construction with limited US production capacity

- Transformer and power electronics Hardening requires identification of failure mechanisms during GMD/GIC/EMP (overvoltage, resonance, pulse duration, pulse rise time, pulse magnitude, compounded by degraded/aged insulation)
  - Technical description of vulnerability is contested (DOD, EPRI, EMP commission, DOE)
  - Significantly reduced break down voltage effect is well documented
  - Multi-physics approach

State of the art approaches for addressing the problem

- Inorganic Insulating Paper
  - Organic binder limits temp



- Polymer insulation systems
  - organic polymer limits temp

- Use of inorganic fibers with high temp organic binders to achieves the best results
- Nomex is the most commonly used high temp polymer insulation
- Kraft paper is the most common insulation in transformers

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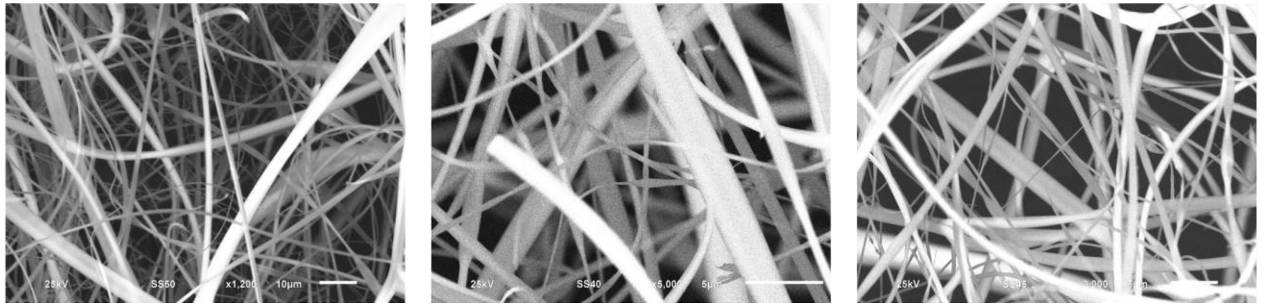
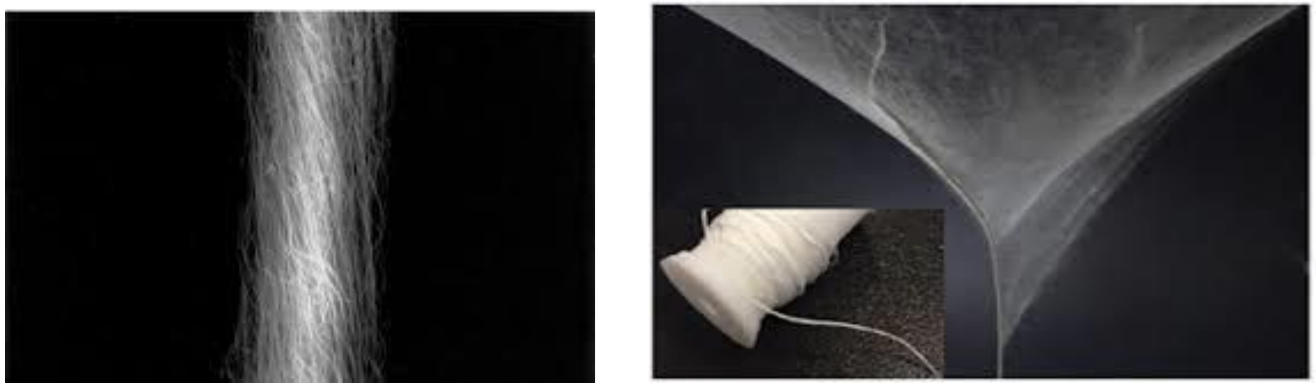
Uniqueness of the proposed solution

- Leverage the properties of electro spun silica nano-fibers
- Mat/felt



- Yarn



- Without organic binders – LDRD project
- Alternate binding strategies - Robust Insulation for Resilient Transformers and Power Electronics project

Significance of the results, if successful

High temp Insulation facilitates expanded design options

- Higher power density-smaller cheaper devices – easier to sock spares
- Materials are more robust facilitating more robust performance
- Vulnerability to multiphysics effects of GMD/GIC/EMP is reduced

LDRD ICORP industry outreach effort identified applications of most interest

- Power electric insulation
- High temp filtration
- Corrosion protection
- Defense contractors (unspecified)
- Utility/manufacturing engineers strongly prefer long proven materials
- Utility managers expressed interest in high temp capabilities

Specific research questions being addressed

What are/is:

- Critical insulation material properties limiting power electronic resilience, performance or design. ***(what's the choke point)***
- Promising composite material components e.g., fillers, binders, etc. that might exceed current technologies in use. ***(what options are out there)***
- The process to fabricate the composite lab samples. ***(How do I make it)***
- The performance characteristics of the new composites and how do they compare to state of the art. ***(Does it work they way we theorized)***
- The new and novel design considerations that can be included in power electronics/transformers for improved equipment performance. ***(What does the data mean to systems the next level up)***
- The role these advanced materials and technologies will play improving cost, size and resilient designs. ***(profit potential?.... Will it be adopted)***

Technical explanation of the proposed approach

Lit review
Consulting
Historic analogy

→

Fabrication of Candidate composites
- Electrospinning
- Post fiber treatment
- Binder matrix

→

Characterization
- BDV
- Resistivity
- Thermal stress tests
- Pull/Bend
- Freq vs dielectric
- SEM, TGA, DSC, XRD

→

Final assessment

Spinning, Gel recipe, Fiber production, are established and on going at INL

Developing an additional treatment step to modify the fibers has historic analogy

Modifying the spinning process to include a binder during fiber production is established in nano-fabrication literature

The characterization tests are well established test methods that are in house at INL or available through one of our partners

Project schedule, deliverables, and current status

Schedule:

- Project start 15-Sep-2019
- Lit review 2-Feb-2020
- Draft Analysis 31-Jan-2021
- Final Report 21-Mar-2021
- Project close 4-Apr-2021

Deliverables:

- Composite selections and rational
- Lab fabrication methods report
- Test data and results with analysis
- Final Report with composite performance and application analysis

Current Status - no tasks complete ~10K funds expended for PR

Anticipated challenges and risk mitigation strategies

- Anticipated challenge:
  modifying the silica fiber such that they adhere to one another in a manner that the bulk properties material properties are mechanically robust while maintaining high temp durability.
- Mitigation:
  Multiple strategies for improving mechanical strength
  -surface modification
  -binders
  -chemical cross linking of fibers
  -fusing fibers

Next steps

- Project kick off
- Initiate down selection of potential material components

Broader Impact

- Publications reporting treatments, crosslinking methods and binders effects on thermal durability vs mechanical strength
- Additional research potential for advanced manufacturing methods
- Synergy impacts expected between the INL LDRD nanofiber insulation project and DOE-OE advanced materials robust insulation project
- LDRD ICORP efforts identified multiple applications which could transition to the products here
- Collaboration between CAES, INL, BSU and UofU

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