Electric Motor Thermal Management

Project ID: ELT214
FY19-FY24, Year 6 of 6
June 5, 2024

PI: Rajneesh Chaudhary (National Renewable Energy Laboratory - NREL); Team: Emily Cousineau, Xuhui Feng, Bidzina Kekelia, Jeff Tomerlin (NREL); Vandana Rallabandi, Mostak Mohammad (Oak Ridge National Laboratory); Iver Anderson (Ames Laboratory); Todd Monson (Sandia National Laboratories); Yogendra Joshi, Satish Kumar, Jubayer Hossain (Georgia Institute of Technology); Bulent Sarlioglu, Thomas Jahns (University of Wisconsin–Madison)

This presentation does not contain any proprietary, confidential, or otherwise restricted information.

OVERVIEW

Timeline

- Project start date: October 1, 2018
- Project end date: September 30, 2024
- Percent complete: 90%

Budget

- Total project funding: $1,500,000
- U.S. Department of Energy (DOE) share: $1,500,000
- Funding for FY 2023: $250,000
- Funding for FY 2024: $250,000

Barriers Addressed

- Cost, power density, and lifetime.

RELEVANCE

This project is part of the Electric Drive Technologies (EDT) Consortium and focuses on NREL's role under the Keystone 2 electric motor project. The research enables compact, reliable, and efficient electric machines.

- Motor 10× power density increase (2025 versus 2015 targets) [1]
- Motor 2× increase in lifetime [1]
- Motor 53% cost reduction (2025 versus 2015 targets) [1].

[1] U.S. DRIVE. 2017. *Electrical and Electronics Technical Team Roadmap*. www.energy.gov/sites/default/files/2017/11/f39/EETT%20Roadmap%2010-27-17.pdf.

SUMMARY

Approach/Strategy

- Supports research enabling compact, reliable, low-cost, and efficient electric machines aligned with roadmap research areas [1].
- Collaborate with ORNL, Ames, and SNL to provide motor thermal analysis support, reliability evaluation, and material measurements on related motor research at national laboratories.
- Collaborate with university partners including Georgia Institute of Technology and University of Wisconsin–Madison to support university-led motor thermal management research efforts.

Technical Accomplishments

- NREL collaborating with Georgia Institute of Technology to develop improved stator winding heat exchangers.
- NREL measuring thermal contact resistances to characterize and establish key contacts needed for thermal analysis of motors.
- NREL providing thermal design support with the help of coupled conjugate heat transfer models for electric machine and power electronics design process led by ORNL.

ACKNOWLEDGMENTS

Susan Rogers, U.S. Department of Energy

APPROACH

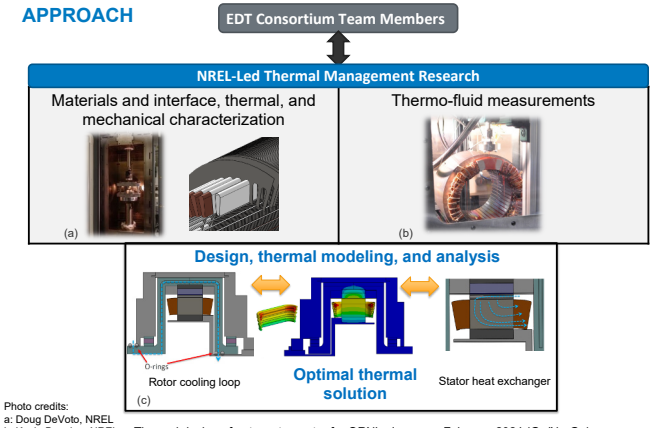


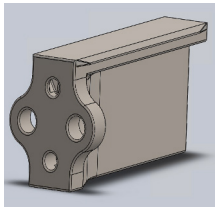
Photo credits:
a: Doug DeVoto, NREL
b: Kevin Bennion, NREL

Thermal design of outer-rotor motor for ORNL: January - February 2024 (Go/No-Go)

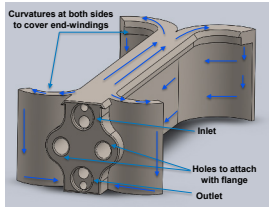
TECHNICAL ACCOMPLISHMENTS AND PROGRESS

Collaboration with Georgia Institute of Technology (ELT251)

- A cooling concept for outer-rotor motors has been co-developed by NREL and Georgia Tech, aiming to directly cool both sides of the motor's end-windings, which represents a meaningful approach to tackling the prevalent hot spots that occur within end-windings.
- Besides significantly reducing the temperature of end windings, this cooling approach is anticipated to yield a similar temperature distribution on both sides of the end-winding, thereby preventing any likely occurrence of substantial temperature gradients.
- The concept can be adapted for integration into existing electric motor designs.



Baseline ceramic heat exchanger for stator winding cooling



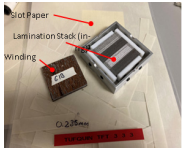
Improved design of the stator winding heat exchanger

Images by Jubayer Hossain, Georgia Tech

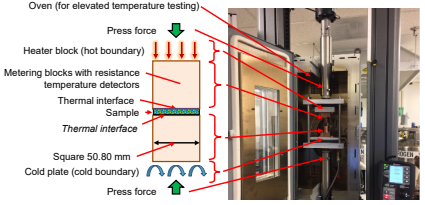
TECHNICAL ACCOMPLISHMENTS AND PROGRESS

Motor Contacts Characterization (ELT214)

- Test plan to characterize thermal contact resistances not currently available in the literature:
  - Winding to slot paper to stator laminations
  - Heat sinks (Al, Cu) to slot paper to winding
  - Heat exchanger (alumina) to stator winding.



Typical experimental samples on hand

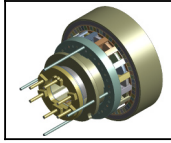
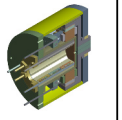
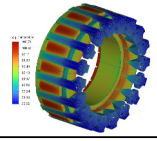


Thermal Transmittance Test Bench to measure thermal conductivity and contact resistance of motor materials

Photos by Emily Cousineau, NREL

Collaboration with Oak Ridge National Laboratory (ELT212/ELT214)

- A conjugate heat transfer (CHT) model of coupled outer-rotor motor and power electronics is being developed at NREL to help benchmark and establish an optimal cooling solution.
- Model includes power electronics and stator winding cooling with separate water-ethylene glycol (WEG) cooling loops, and air cooling of magnets between the rotor-stator gap and behind the rotor.
- Outer-rotor motor has higher windage losses as estimated by the model due to its unique design, and therefore requires a novel solution to cool magnets at higher rotational speeds.
- Model includes viscous heating to refine estimates on rotor windage losses.
- Model is being used to investigate various cases and look at parametric assessment to help optimize cooling of the outer-rotor motor.
- Motor is currently being fabricated, and test runs are being planned by the end of this fiscal year. The CHT model estimates will be validated/calibrated with the test results.
- Models will be calibrated and improved based on the learnings from the test runs to improve their predictability for future outer-rotor motor designs.

Integrated outer rotor drive	Half-symmetry view	Temperature around stator windings, lamination, and WEG-cooled ceramic heat exchangers (6,666 RPM, 58 kW)
		

FUTURE WORK

- In collaboration with ORNL, build prototype heat exchanger to verify expected cooling performance in relation to the non-heavy-rare-earth, high-speed motors research effort led by ORNL.
- Continue supporting thermal design and performance assessment of high-speed motor for ORNL with the help of complete motor conjugate heat transfer models.
- Continue experimental work at NREL to quantify thermal contact resistances - that are not readily available in the literature - between materials for motors.
- Support Georgia Institute of Technology in efforts to model motor thermal management concepts, conduct experiments, and publish motor thermal management research results.
- Continue meetings and discussions with the University of Wisconsin–Madison to provide technical support, thermal data, and material information to support integrated cooling of motor and power electronics.

Any proposed future work is subject to change based on funding levels.

COLLABORATIONS

Oak Ridge National Laboratory (ORNL)

- NREL collaborating on electric motor design efforts led by ORNL.
- NREL supporting thermal modeling and simulation analysis for motor and material performance trade-off studies.

Sandia National Laboratories (SNL)

- NREL supporting material thermal and mechanical property measurements for material research efforts led by SNL.

Ames Laboratory

- NREL continuing discussions with Ames to support material development efforts led by Ames.

Georgia Institute of Technology

- NREL providing technical support, geometry data, thermal modeling data, and experimental data to support evaluations of advanced cooling impacts.
- NREL and Georgia Tech working to develop next-generation stator winding heat exchangers with improved performance.

University of Wisconsin

- NREL providing technical support, thermal data, and material information to support integrated cooling of motor and power electronics.

For more information, contact:

NREL EDT Task Leader

Sreekant Narumanchi
Sreekant.Narumanchi@nrel.gov
Phone: 303-275-4062

NREL Principal Investigator

Rajneesh Chaudhary
Rajneesh.Chaudhary@nrel.gov
Phone: 303-384-7351

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Vehicle Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

DOE Vehicle Technologies Program
2024 Annual Merit Review and Peer Evaluation Meeting
June 3-6, 2024
NREL/PO-5400-89511