Integrated Traction Drive Thermal Management

Keystone Project 3

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Project ID: ELT217

OVERVIEW

Timeline

- Project start date: 10/01/2018
- End date: 09/30/2023
- Third year in a five-year project.

RELEVANCE

Objectives

- Research and evaluate motor-integrated power electronics packaging technologies and thermal management approaches.
- Provide support to ORNL and University of Wisconsin teams in thermal management modeling and design of their integrated traction drives.

Project Impact

- Identify pathways enabling high-performance, compact, and reliable integrated electric drives.
- Help achieve DOE 2025 target of 33-kW/L system power density for an electric traction drive.

SUMMARY

Approach/Strategy

- Research state-of-the-art thermal management solutions for integrated electric traction drives.
- Identify component geometries and solutions based on publicly accessible scientific literature, published original equipment manufacturer (OEM) materials, interactions with automotive industry, and collaboration with research labs and universities.
- Use combination of various cooling strategies for most efficient heat removal from integrated traction drive components: water-ethylene-glycol flow in internal channels, automatic transmission fluid (ATF) jet impingement on stator winding end-turns, usage of high thermal conductivity/low thermal resistance component assemblies, and direct cooling with dielectric fluids.

Technical Accomplishments

- Modeling and design of thermal management system components for ORNL and University of Wisconsin integrated traction drives are underway.

COLLABORATION AND COORDINATION

- Oak Ridge National Laboratory (ORNL)
- University of Wisconsin
- Ames Laboratory

APPROACH

Design of a thermal management solution appropriate to each collaborating team's selected integrated drive concept

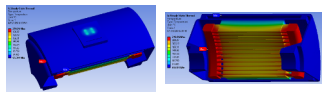
- Keep electric motor and power electronics temperatures within selected material operating limits
- Modeling results to inform efficient design of power electronics integration solutions
- Design combined cooling system for electric motor and integrated power electronics
- Preferably a single fluid loop approach to enable the integrated cooling system for inverter + motor.

Material selection for the cooling system components is very important

- Transparent for electromagnetic field to minimize interference with electric motor operation
- Electrically isolating to avoid short-circuiting electrically sensitive parts and ensure reliable phase separation of windings
- Thermally conductive to improve heat removal from heat-generating components of the integrated drive.

Software tools and modeling capabilities

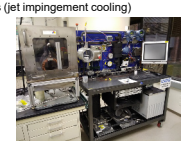
- NREL has access to commercial computer-aided design (CAD), finite element analysis (FEA), and computational fluid dynamics (CFD) numerical modeling software for thermal modeling
- Thermal modeling is used to inform design solutions



Thermal modeling sample of integrating cooling system. Images by Bidzina Kekelia (NREL)

Experimental capabilities

- Large fluid loop test bench for measuring convective heat transfer coefficients (jet impingement cooling)

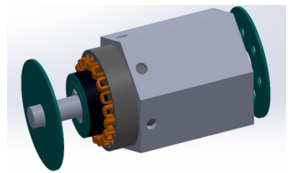


Large fluid loop test bench. Photo by Bidzina Kekelia (NREL)

ACCOMPLISHMENTS AND PROGRESS

University of Wisconsin integrated traction drive

- NREL is supporting development of the University of Wisconsin's integrated traction drive
- Providing technical support, thermal data, and material information to support integrated thermal management system design for cooling electric motor and power electronics.

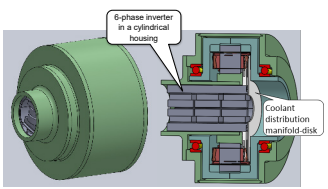


Preliminary design concept of University of Wisconsin's integrated traction drive. Image courtesy of the University of Wisconsin

ACCOMPLISHMENTS AND PROGRESS (CONTINUED)

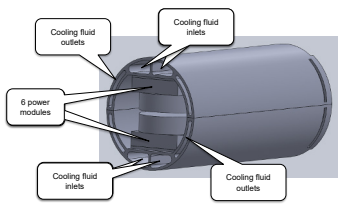
ORNL integrated traction drive

- Working on a single loop cooling concept for ORNL outer-rotor motor with integrated power electronics in its central cavity.
- Working to reconfigure coolant distribution manifold-disk to heat exchanger attachments



Preliminary design concept of ORNL's integrated traction drive with inverter in central cavity. CAD design by Randy Wiles, Jon Wilkins, Tsarafidy Raminosoa (ORNL), and Bidzina Kekelia (NREL)

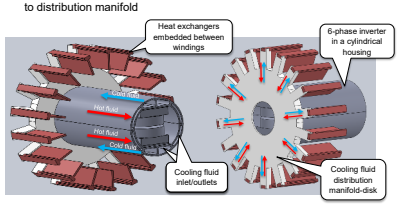
- Designed cylindrical housing for power electronics integration into central cavity of the electric motor.
- The cylindrical housing incorporates internal channels for coolant flow. It serves a dual purpose for removing heat from the power electronics and stator's internal surface, and providing coolant to phase-separator heat exchangers embedded in the windings.



Preliminary design concept of a cylindrical inverter housing with cooling fluid channels in the walls. CAD design by Bidzina Kekelia (NREL)

Evaluating options for manufacturing cooling system components

- 3D-printing heat exchangers with high conductivity polymer (8–10 W/m-K)
- Ceramic (Al_2O_3 with 28–35 W/m-K) phase separator heat exchangers embedded between stator windings
- 3D-printing fluid distribution manifold from polymer
- Extruded aluminum heat exchanger for inverter housing
- Direct ceramic bonding versus adhesive attachment of heat exchangers to distribution manifold

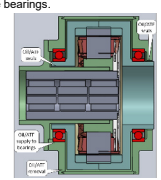


Preliminary design concept of a single fluid loop cooling system for ORNL's integrated traction drive. CAD design by Bidzina Kekelia and Emily Cousineau (NREL)

FUTURE WORK

ORNL – cooling and lubrication of bearings

- Large-diameter bearing used in current design requires oil lubrication for 20,000-rpm operation. Oil lubrication would simultaneously provide cooling for the bearings.



Future focus area for bearing lubrication and cooling. Image by Bidzina Kekelia (NREL)

University of Wisconsin – considering cooling concepts

- Discussions are ongoing on selection of optimal cooling concept:
  - Combined: air + oil/ATF cooling
  - Combined: air + water cooling jacket
  - Oil/ATF spraying/impingement cooling of windings.

Experimental

- Planning to build a smaller fluid loop for lower flow rates and smaller thermal inertia for jet impingement cooling characterization.
- Extend characterization of ATF jet impingement cooling by investigating the impact of jet incidence angles, as well as the distance between the nozzle and the target surface.

Experimental measurements of ATF jet impingement heat transfer coefficients. Photo by Bidzina Kekelia (NREL)

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

CHALLENGES AND BARRIERS

- Gathering information on proprietary motor-integrated power electronics and thermal management solutions (not readily available or open-source) for evaluation and comparison
- Heat extraction from power-dense electric traction drive and integrated power electronics with a single cooling system
- Leak-free sealing of cooling system components is challenging.

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