Power Electronics Thermal Management

Gilbert Moreno (PI), Rajneesh Chaudhary, Josh Major, Sreekant Narumanchi, Jeff Tomerlin, and Shuofeng Zhao
National Renewable Energy Laboratory

Project ID: ELT211
FY19–FY24: Year 6 of 6

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

OVERVIEW

Timeline

- Project start date: FY 10/1/2018
- Project end date: FY 9/30/2024
- Percent completed: 90%

Budget

- Total project funding: $ 1,900,000
  - DOE share: $ 1,900,000
- Funding for FY 2023: $ 250,000
- Funding for FY 2024: $ 250,000

Barriers

- Size and weight, cost, performance and lifetime

RELEVANCE

- Thermal management is essential to increase power density and reliability.

Project Objectives

- Develop thermal management techniques to enable achieving the (year 2025) DOE 100-kW/L power density target.
- Enable high-temperature (250˚C) and high-heat-flux wide-bandgap power electronics.

SUMMARY

Approach

- Develop single-phase heat transfer, dielectric fluid cooling strategies to decrease junction-to-fluid thermal resistance and enable increased power density.

Technical Accomplishments

- Evaluated the transient performance of the dielectric fluid concept using drive cycle profiles.
- Sized an air-cooled heat exchanger for the dielectric fluid concept and compared its size to that of a WEG-to-air heat exchanger.
- Initiated long-term reliability experimental evaluation of the dielectric fluid and heat exchanger.
- Developed electrical models to evaluate the effect of the dielectric fluid on electrical performance.

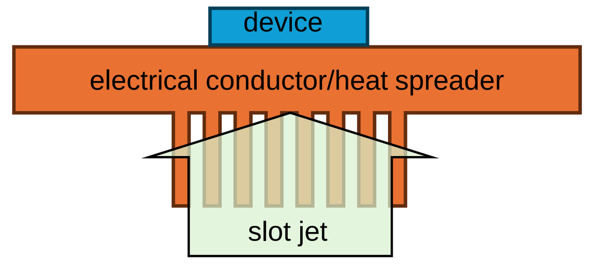
APPROACH

Motivation

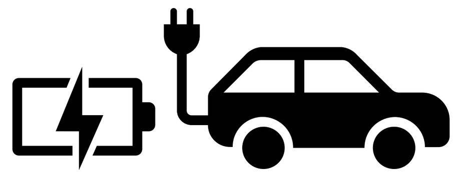
Package conduction resistance is the dominant resistance for existing power modules. Dielectric fluids enable a redesign of the package to minimize package resistance (i.e., eliminate the ceramic), allow for bus bar cooling, eliminate expensive ceramic substrates, and enable use of new automatic transmission fluid (ATF)-like fluids for direct cooling of power electronics modules.

Dielectric Fluid Cooling (Single Phase) of Power Electronics

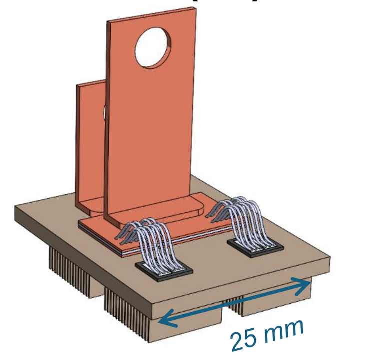
Basic concept



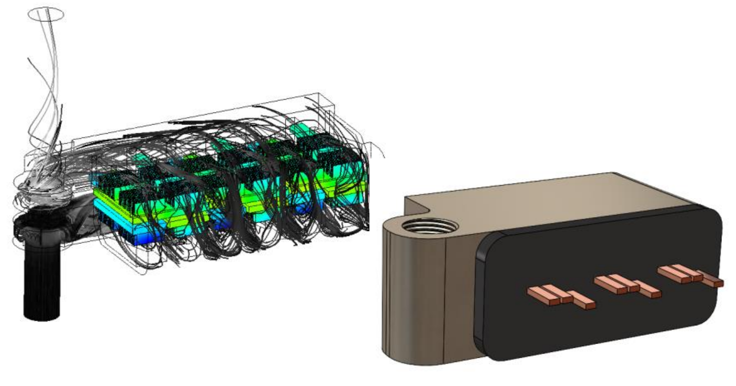
Using dielectric fluids intended for electric vehicles (EVs)



Silicon carbide (SiC) module

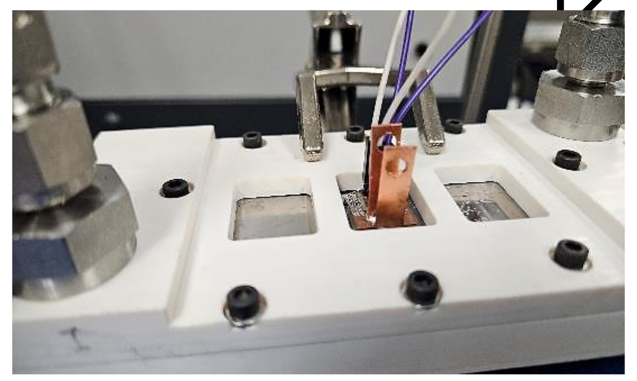


Developed jet impingement concepts to enhance thermal performance → Evaluated new EV driveline fluids to use as coolants → Experimentally demonstrated the concept using a SiC module and showed performance improvements compared with water-ethylene glycol (WEG)



Double-side-cooled, dielectric fluid concept (total volume ~240 mL)

Collaborating with Infineum



SiC module and dielectric fluid heat exchanger

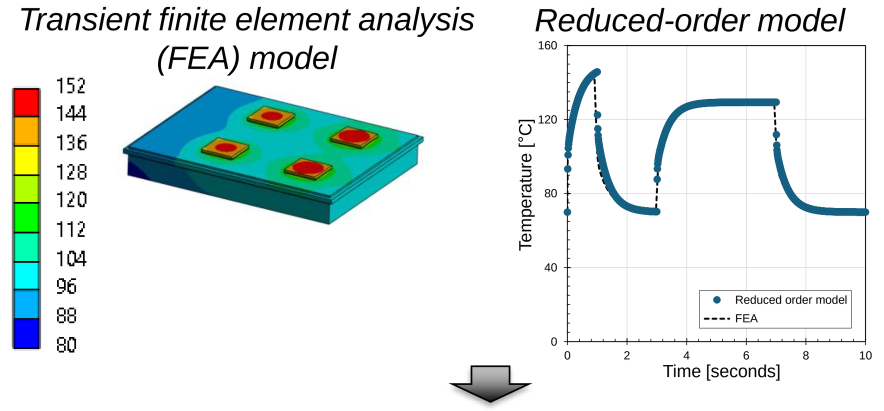
Current Work

- System-level analysis (steady-state and transient) and design.
- Long-term reliability evaluation of the dielectric fluid and heat exchanger.
- Evaluate effect of the dielectric fluids on electrical performance.

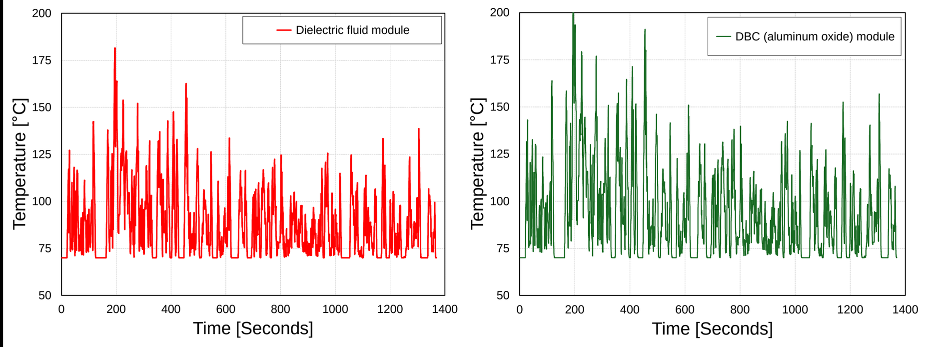
TECHNICAL ACCOMPLISHMENTS AND PROGRESS

Dielectric Module Transient Analysis

Transient finite element analysis (FEA) model | *Reduced-order model*



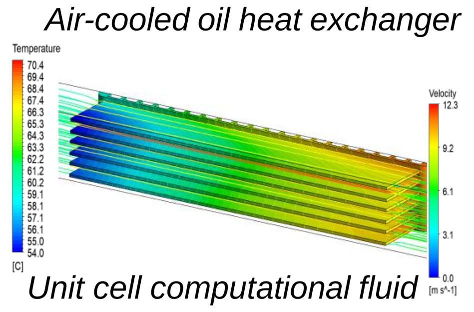
Predicted temperatures for a drive cycle (UDDS drive cycle for 2017 Chevy Bolt EV) using reduced-order model



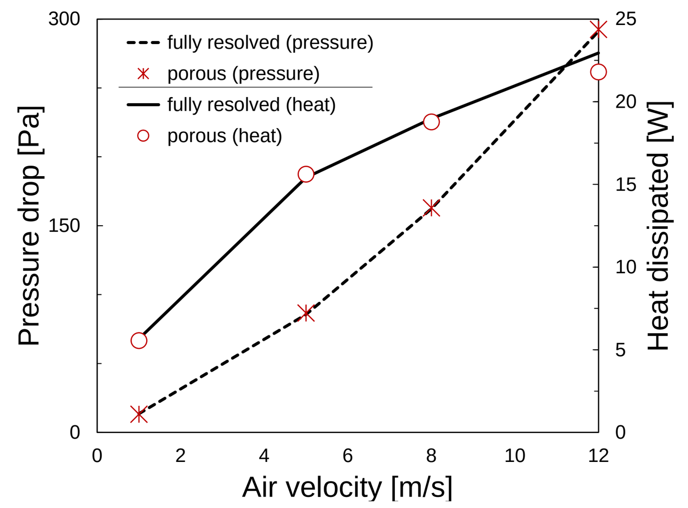
Use results to predict temperature cycles and evaluate for reliability

Dielectric Fluid Heat Rejection Analysis

Air-cooled oil heat exchanger



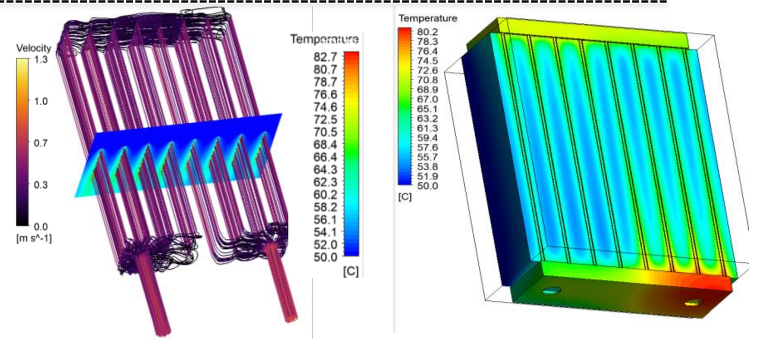
Unit cell computational fluid dynamics (CFD) model



Used a unit-cell, fully resolved CFD model to calibrate a porous media model of the heat exchanger

Developed full-scale thermal model of the dielectric fluid, air-cooled heat exchanger

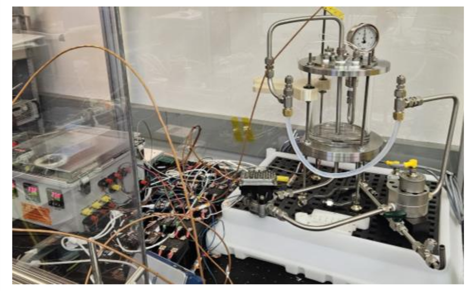
- Predict that an 18 cm × 23 cm (frontal area) heat exchanger can reject 2.2 kW of heat



Full-scale CFD model of dielectric fluid-to-air heat exchanger

System-level, transient thermal model to evaluate various operating conditions (e.g., drive cycles)

Long-Term Reliability Evaluation



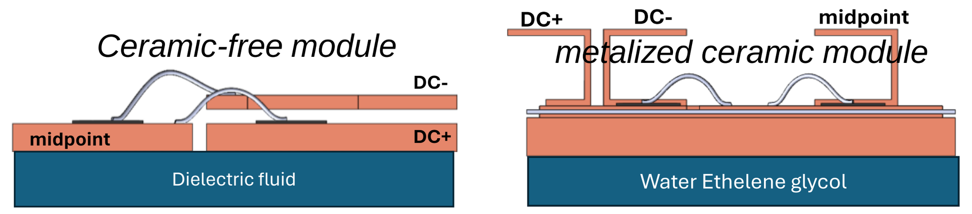
Evaluating the long-term reliability of the dielectric fluid and heat exchanger:

- Expose fluid to elevated temperatures and an electric field.
- Evaluate dielectric fluid reliability by measuring fluid properties.
- Measure heat exchanger thermal resistance to determine its reliability.
- Evaluate for material and fluid compatibility.

Breakdown Voltage [kV]	Viscosity [cSt]	Specific Heat [J/kg-K]	Thermal conductivity [W/m-K]
37.2	3.984	2,534	0.156

Measured AmpCool-110 properties at 70°C and initial conditions

Electrical Performance Evaluation



Through modeling, we are evaluating the effect of the dielectric fluid cooling concept on electrical performance.

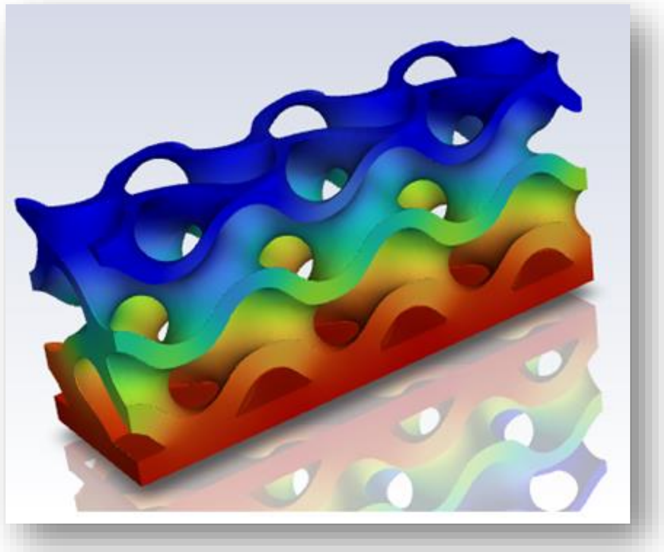
FUTURE WORK/CHALLENGES AND BARRIERS

- Complete electrical simulations to evaluate the effect of the dielectric fluid concept on electrical performance.
- Complete the dielectric fluid reliability evaluation.
- Complete the system-level modeling work.
- Collaborate with Georgia Tech to evaluate and develop the advanced cooling technologies.

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

COLLABORATIONS

- Collaborating with Georgia Tech (Professor Y. Joshi and Ubade Kemerli) to evaluate the use of gyroid (triple period minimal surface [TPMS]) structures as surface enhancement structures for dielectric fluid heat exchangers.



Gyroid structures were evaluated under various dielectric fluid flow configurations. Initial results predict improved thermal performance compared with existing, linear fin design.

- Collaborating with Infineum (Ryan Rieth, Sonia Oberoi, and Scott Campbell) to evaluate new driveline fluids being developed for EV, direct cooling applications.
- Collaborating with SUNY Poly (Woongje Sung) to use their SiC devices in our demonstration modules.
- Collaborating with Oak Ridge National Laboratory to understand the effects of dielectric fluids cooling strategy on device electrical performance.

ACKNOWLEDGMENTS

Susan Rogers, U.S. Department of Energy

NREL EDT Task Leader

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

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's 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.

Vehicle Technologies Office Annual Merit Review
Arlington, VA
June 3–6, 2024
NREL/PR-5400-89404