U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Air Cooled Traction Drive Inverter

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Project ID: APE042

2012 U.S. DOE Hydrogen and Fuel Cells Program and Vehicle Technologies Program Annual Merit Review and Peer Evaluation Meeting

Overview

Timeline

- **Project start – Oct. 2009**
- **Project end – 2015**

Budget

- **Total project funding**
  - **DOE 100%**
- **FY10 - $361K**
- **FY11 - $0K**
- **FY12 - $200K**

Barriers

- **Barriers**
  - Achieving the 2015 VTP power density target and cost target for an inverter using air-cooling.
  - Acquiring high temperature devices and passive components
- **Vehicle Technologies Program 2015 Targets**
  - **12 kW/l, 5 $/kW and 12 kW/kg**

Partners

- **ORNL team members: Randy Wiles**
- **NREL team: Jason Lustbader**

Objectives

- To demonstrate the feasibility of air cooling for traction drive power electronics while achieving 2015 VTP targets.

Milestones

- **FY10**
  - **Completed the study to determine the feasibility and boundary conditions (such as ambient conditions, fan power, etc.) required for a 55 kW peak/30 kW continuous power rated inverter with air cooling.**
  - **Go No/Go Decision Point: Does the 55-kW air-cooled inverter design concept meet the 2015 VTP power density target.**
- **FY11**
  - **Project suspended to allow for heat transfer developments by NREL.**
- **FY12**
  - **Simulate the air cooled inverter concepts: Improve design and evaluate the module and down select the inverter.**
  - **Revise the models based on thermal system performance from NREL.**
  - **Go No/Go Decision Point: Does the design meet the volume and cost targets.**

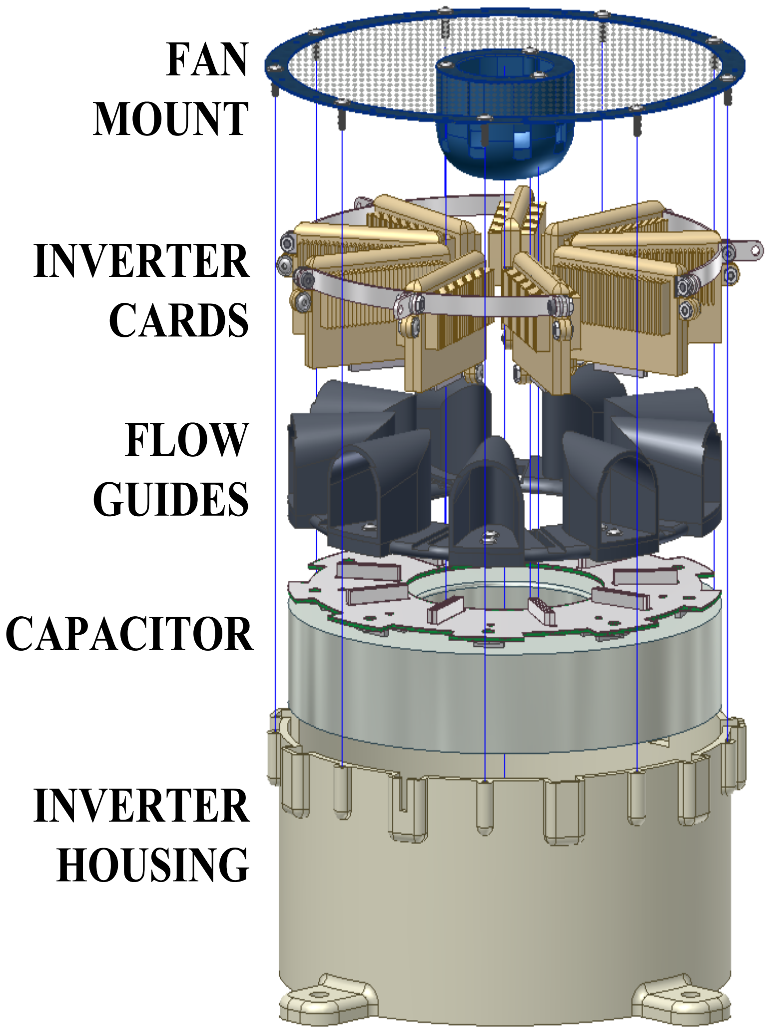
Technical Approach

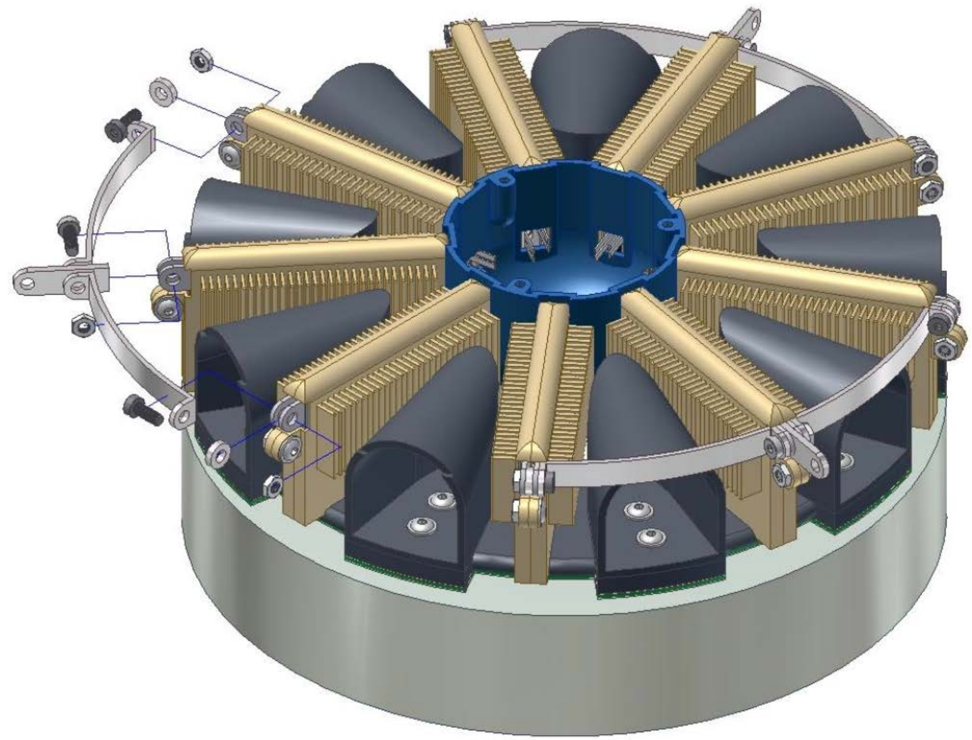
- **Design innovations:**
  - ✓ Thermal insulating material to separate the low temperature components from the high temperature zone.
  - ✓ Utilizes the high temperature operating capability of wide bandgap (WBG) devices.
  - ✓ New low-loss Si IGBTs.
  - ✓ Innovative heat sink design minimizes the thermal resistance.
  - ✓ Fewer wire/ribbon bonds to increase the reliability of the inverter and decrease the package inductance.
  - ✓ Alternate die-attach approach for high temperature devices.

Technical Accomplishments-FY10

Inverter Design Layout

Exploded view of the final axial inflow inverter

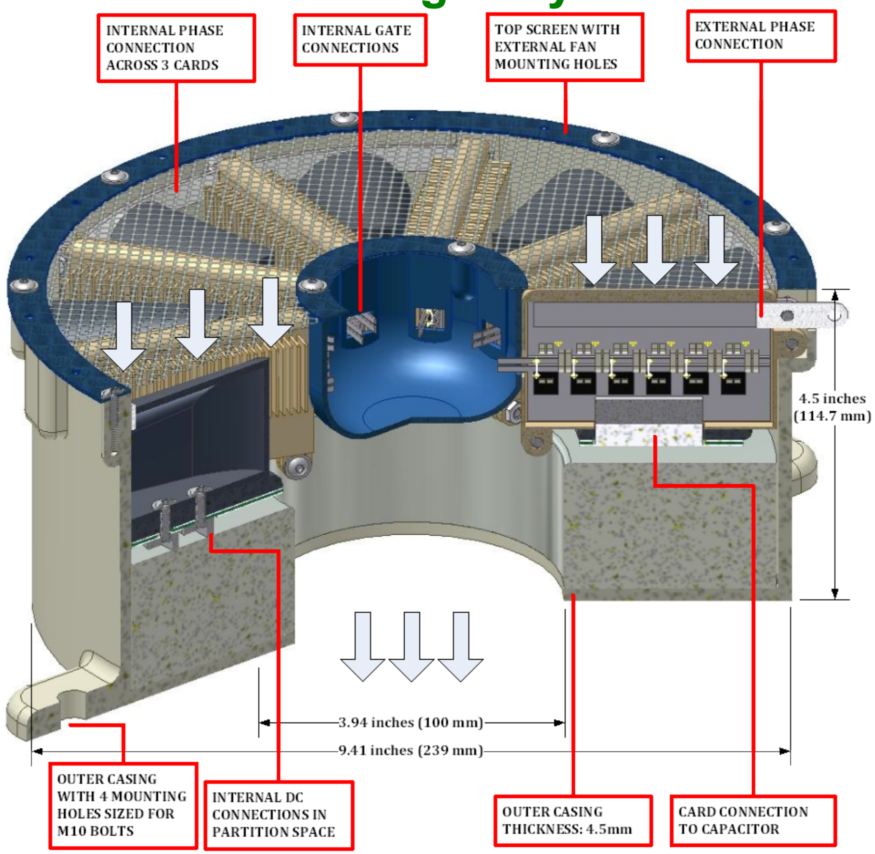


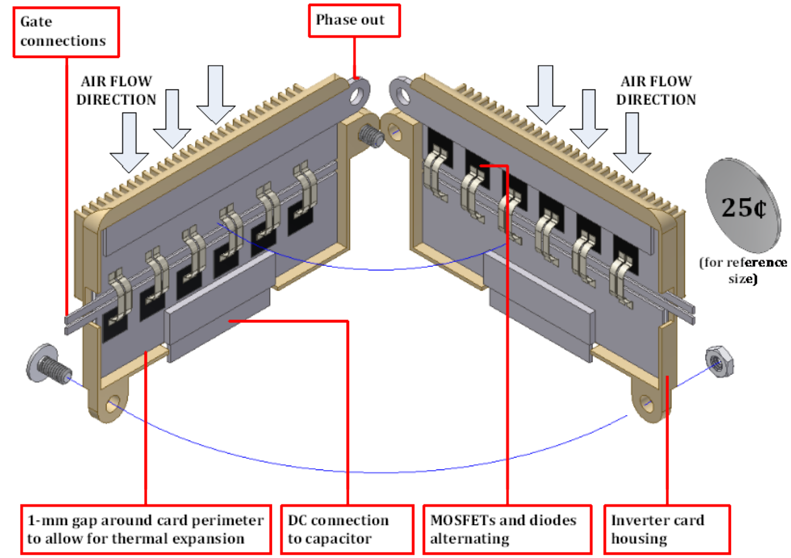


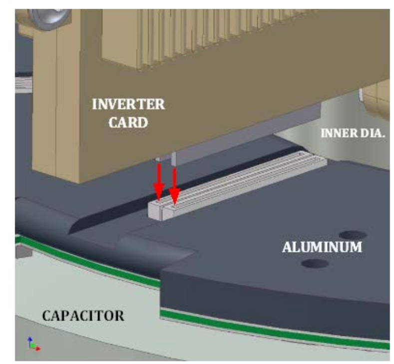
Patent pending design

Technical Accomplishments-FY10

Inverter Design Layout





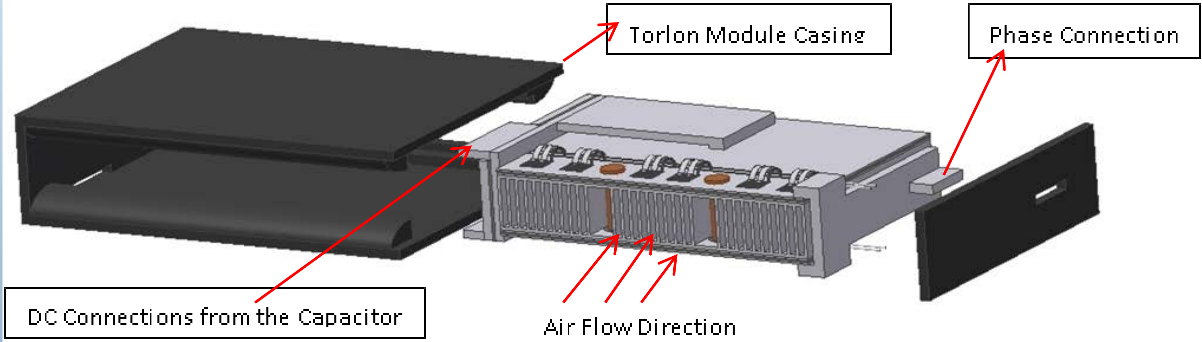


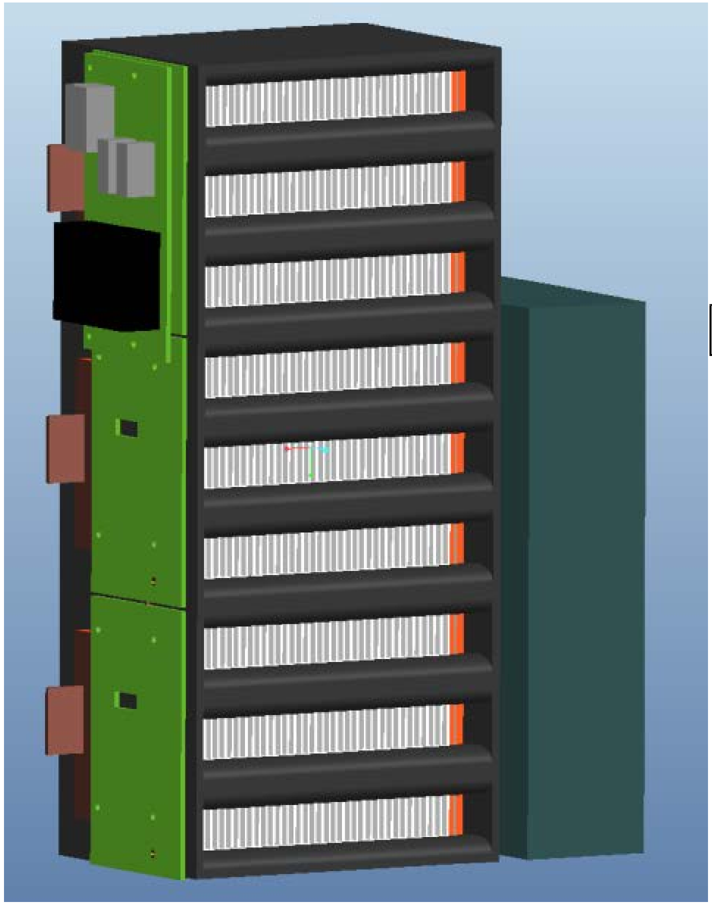
- Flow guides ensure that the air flows effectively around the fins without adversely affecting the pressure drop.
- The inverter outer diameter and height are 239 mm (9.4 in.) and 115 mm (4.5 in.), respectively.
- The total volume of the inverter is 5.1 liters (313 cubic inches).
- Each substrate is housed inside an aluminum structure having 30 cooling fins on each of the two outside surfaces for cooling by air.
- The top of the DBA structure is segmented to connect to the capacitor on the lower half, a gate driver in the middle, and the external phase connection on the upper half.

Patent pending design

Technical Accomplishments-FY10

Isometric exploded view of the module assembly.



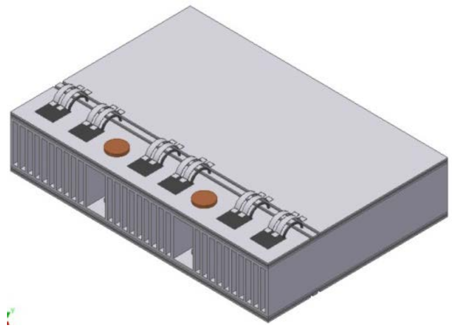


Isometric view of the entire rectangular inverter

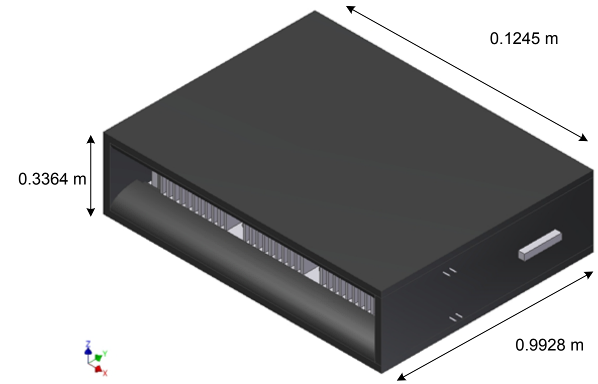
- The volume of one module is 0.416 L.
- The volume of a stack of 9 modules is 3.74 L.
- The volume of the entire rectangular inverter (with rectangular capacitor 1.34 L) is 5.1 L.

Patent pending design

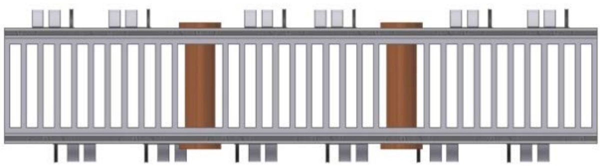
Technical Accomplishments-FY10



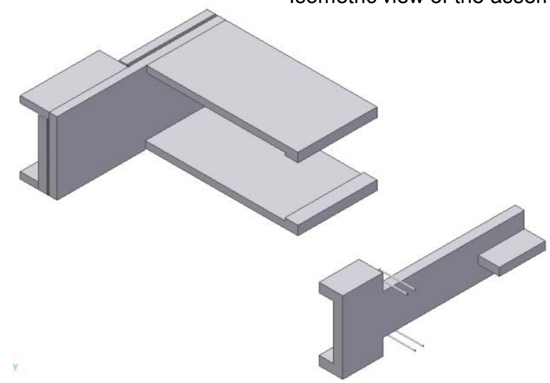
Isometric view of the phase module.



Isometric view of the assembled module.



Front view of the assembled module.



Electrical connections in the module

- The assembled module consists of two DBA cards soldered onto the flow channel. The aluminum flow channel is electrically insulated from the DC + and DC – traces by the aluminum nitride substrate. The phase trace is connected by the copper bolts.

- There are six devices on the top trace and six on the bottom trace as well. Twelve devices per module were used to lower the current per device.

Patent pending design

Technical Accomplishments-FY10

Comparison of Tj for steady-state and transient simulations

Inverter	Tamb (C)	Steady State		Full transient US06 Drive Cycle+
		Current (A)	Tj (° C)	Tj (° C)
Axial	50	240	> 274**	142
Rectangular	50	240	> 252*	111

+ full transient simulation of the two inverter designs for the most demanding of the parametric cases with V = 650 V, fsw = 20 kHz, Q = 30 CFM, and Tinlet = 50° C.

* the value for Q = 40 CFM; At Q = 30 CFM, expect Tj > 252° C
** the value for Q = 50 CFM; At Q = 30 CFM, expect Tj > 274° C

Comparison of the performance of the two inverter design packages

	Axial	Rectangular
Power Density (kW/l)	12.4	12.01
Pressure Drop (in.H2O) @ 30 CFM	1.3	0.436
Pressure Drop (in.H2O) @ 60 CFM	5.0	1.64
Ideal Blower Power (W) @ 30 CFM	40.3	13.9
Ideal Blower Power (W) @ 60 CFM	312	104.5

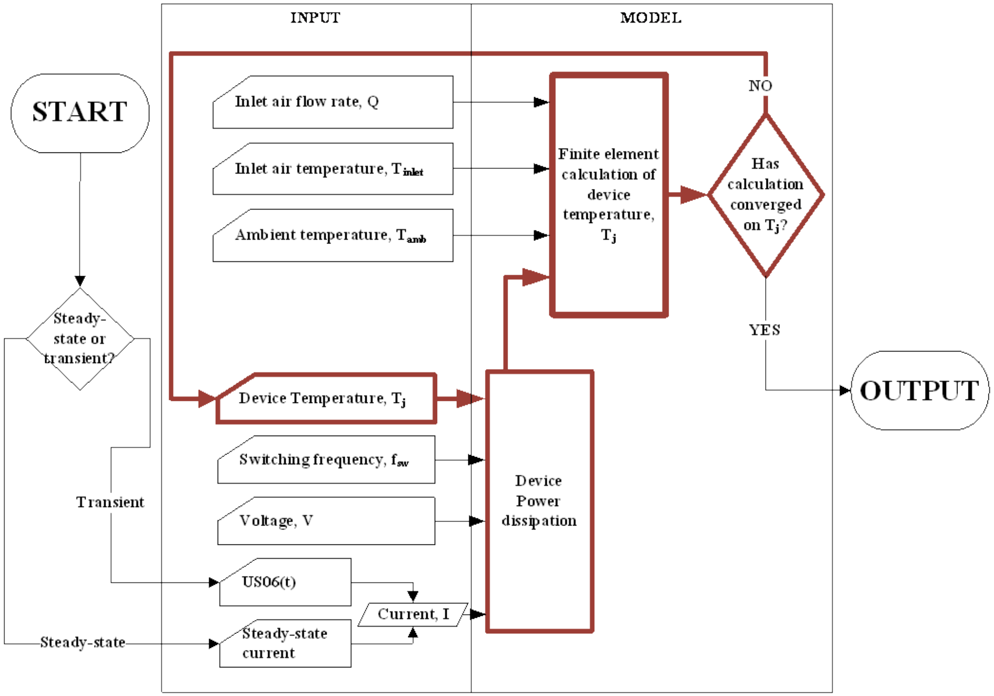
The total volume of axial and rectangular inverters is 5.1 liters !

Technical Accomplishments – FY12

- Sent the CAD models of the rectangular inverter to NREL for thermal evaluation and validation.
- Sent the device models for heat generation curves and the design methodology for sizing the inverter to NREL.
- Updating the device models with new SiC MOSFET 1200 V, 200 A data.

  - reduction in number of die-lower cost

- A new air-cooled inverter design with reduced blower power requirements was completed.
- New module design utilizing four different techniques were identified.



Updated thermal test results of the selected module- APE019

Collaboration and Coordination with Other Institutions

- NREL: Thermal modeling
- Industrial suppliers of WBG and Si devices.

Future Work

- **FY12**
  - Revise the models based on the balance of plant results from NREL.
  - Complete design optimization of the modules.
- **FY13**
  - Refine the air-cooled inverter models developed in FY12-colloborate with NREL.
  - Design high temperature modules and the gate driver.
  - Build and test high temperature modules.
  - Perform electrical parameter evaluation and control electronic design.
  - Build and test a 10 kW prototype electrical module.
  - Send the module to NREL for detailed confirmation of thermal testing
  - Identify the technical challenges and finalize the design to build a 55kW prototype.
- **FY14**
  - Build and test prototype full inverter system.

Summary

- ORNL has shared models and data with NREL for thermal evaluation.
- A new air-cooled inverter design with reduced blower power requirements was completed.
- The inverter designs are being modified using new high temperature devices.
- New module designs utilizing four different techniques were identified.