U.S. DEPARTMENT OF ENERGY

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

High-Temperature Air-Cooled Traction Drive Inverter Packaging

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Project ID: APE025

Overview

Timeline

- Project start – Oct. 2009
- Project end – Sep. 2010
- Percent complete – 50%

Budget

- Total project funding
  - DOE 100%
- FY10 - $361K

Barriers

- Barriers
  - Availability of higher current rated WBG devices.
  - Availability of high temperature passive components.
- Vehicle Technologies Program Targets
  - DOE 2020 inverter target: 13.4 kW/l
  - DOE 2020 inverter target: 3.3 $/kW

Partners

- University of Tennessee
- NREL

Objectives

- To demonstrate the feasibility of air cooling for power electronics while achieving DOE Vehicle Technologies Program 2020 inverter targets.

- To reduce the cost for cooling power electronics by eliminating the liquid cooling system.

Milestones

- Complete 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: project ends September 2010.

Technical Approach

- The project was re-scoped in FY10 from designing an inverter prototype to the study of boundary conditions (such as ambient conditions, fan power, etc.) required for a 55 kW peak/30 kW continuous power rated inverter with air cooling.

- Refine the air-cooled inverter models:
  – Thermal and fluid simulations on selected inverter architectures to predict the performance of the heat removal system
  – Improvements to the geometric and airflow configuration developed during FY09 under the Wide Bandgap project (APE007).

- Develop knowledge base to define requirements of the components in the inverter to meet VTP 2020 inverter targets (volume, weight, cost) using a baseline inverter design.

Technical Accomplishments – FY09

	Maximum Device Temperature (°C)							
	200		225		250		275	
Ambient temperature (°C)	Average *h* (W/m²/K)	*Average capacitor temperature* (°C)	Average *h* (W/m²/K)	*Average capacitor temperature* (°C)	Average *h* (W/m²/K)	*Average capacitor temperature* (°C)	Average *h* (W/m²/K)	*Average capacitor temperature* (°C)
50	71.3	70.7	53.3	81.8	42.2	94.8	35.1	109.3
55	76.3	73.7	56.3	84.5	44.3	97.1	36.4	111.3
60	81.9	76.8	59.5	87.1	46.3	99.4	37.7	113.3
65	88.3	80.0	63.0	89.9	48.5	101.8	39.2	115.4
70	95.8	83.3	66.9	92.8	50.9	104.3	40.8	117.6
75	104.4	86.7	71.3	95.7	53.5	106.8	42.5	119.8
80	114.6	90.2	76.3	98.7	56.3	109.5	44.3	122.1
85	126.8	93.8	81.9	101.8	59.5	112.1	46.3	124.4

Green cells are indicative of results for cases which have < 100 W/m²/K and Tcap-ave < 100°C (feasible).
Yellow cells represent results for cases which either have < 120 W/m²/K or Tcap-ave < 120°C (can be considered)
Red cells represent results for cases which either have > 120 W/m²/K or Tcap-ave > 120°C (not feasible)

- **The initial feasibility study using conduction model of the air cooled inverter (voltage source topology with no boost converter) was completed.**
- **The analysis showed that there is a wide range of feasibility for several operating conditions and the limitations were certainly the capacitor temperature even though the average h was acceptable.**

Technical Accomplishments - FY09

Performance Parameter	Units	Design A	Design B	Design C
$T_{device,max}$	°C	380	270	204
$T_{cap,max}$	°C	120	103	74
Pressure Drop	Pa	3400	3800	3473
Pressure Drop	In.H_2O	13.6	15.2	13.9
Blower Power Input for Inverter	W	936.4	1046.5	967.2
	hp	1.23	1.4	1.3

Inlet airflow velocity 6 m/s, Inlet air temperature 50 ℃, volumetric flow rate of 0.0306 m3/s or 64.84 cfm.
Design A –No fins; Design B – 6 fins per phase leg; Design C – 9 fins per phase leg

- **The air flow model (turbulent flow field) was developed for heat transfer calculations.**
- **Initial feasibility study shows that a 55 kW inverter with air cooling is possible, achieving 12 kW/l (2015 target) power density with device junction temperatures around 200°C.**

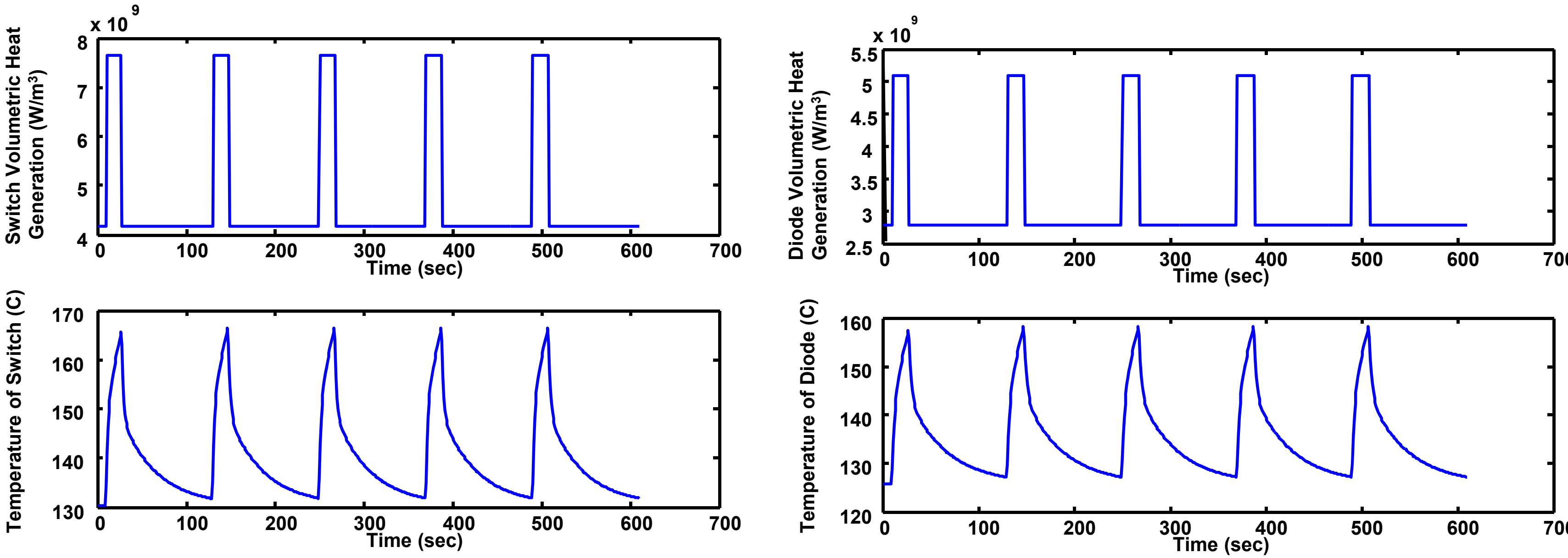
Technical Accomplishments - FY10

	Inflow Configuration	
Description	Configuration I Design A	Configuration II Design A
Pressure Drop (in. H_2O)	13.6	11.8
Max. Device Temperature (°C)	380	272
Max. Air Temperature (°C)	206	170
Max. Capacitor Temperature (°C)	119	95

Inlet airflow velocity 6 m/s, Inlet air temperature 50 ℃, volumetric flow rate of 0.0306 m3/s or 64.84 cfm.
Configuration I –Radial; Configuration II - Axial

- **Two different air flow configurations were used on a similar design to analyze the effect of air flow pattern.**
- **The maximum temperature of the device and the pressure drop for configuration I were reduced by 110°C and 1.8 in. H_2O compared to Configuration II.**

Technical Accomplishments – FY10



- A model that includes a volumetric generation rate as a function of time was developed for transient analysis.
- For a periodic step input which includes 120s (18 seconds of 55 kW and rest was 30 kW) the resultant temperature of the devices was calculated.
- This computational model is very informative because it enables the study of dynamic thermal behavior of a given system for different power inputs.
- The surface temperature of the device was significantly reduced to 167 °C (about 37 °C less) compared to 204 °C at steady–state power input of 55 kW.

Collaboration and Coordination with Other Institutions

- University of Tennessee: Thermal modeling of the air-cooled inverter designs using FEA.
- NREL: Balance of plant thermal modeling.

Future Work

- **FY10**
  - Continue to refine the air cooled inverter models developed in FY09 by performing thermal and fluid simulations on selected inverter architectures.
  - Complete the study to determine the boundary conditions (such as ambient conditions, fan power, etc.) required for a 55 kW peak/ 30 kW continuous power rated inverter with air cooling.
  - ORNL will await the results of balance of plant thermal modeling from NREL to determine if this project should be continued in the future.

Summary

- Completed the initial feasibility study of a 55 kW air cooled inverter to demonstrate air cooling was possible for a wide range of operating conditions.

- Analyzed two different air flow configurations on a similar air cooled inverter design to evaluate the effect of air flow pattern to reduce the parasitic fan power.

- Studied the air cooled inverter for transient system response to determine the heat dissipation of the power devices for 30 kW continuous power to 55 kW peak power excursion.