Power Electronic Thermal System Performance and Integration

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Project Duration: FY08 to FY10

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Advanced Power Electronics and Electric Machines Projects
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This presentation does not contain any proprietary or confidential information
The Problem

• Thermal control is a critical factor in PEEM performance.
• Today’s vehicles use a dedicated 70°C PEEM cooling system.
  − Cost is about $175 to consumer.
• PEEM target cost is $440 for 55 kW system ($8/kW).
• Cooling system represents 40 percent of system cost.

Conclusion

Cannot afford dedicated cooling system.
The Problem

- Commercially viable thermal control technologies must minimize the overall system complexity, cost, volume, and weight while maintaining performance and reliability.

- What are feasible system design directions?

- What analysis tools can speed up R&D evaluations prior to hardware builds?

- How close are breakthrough technologies?
Description of Technology

- Thermal systems integrate:
  - Thermal R&D efforts
  - PE performance data
  - Vehicle systems
  - PE reliability

**What?**

1) Parametric 3D FEA thermal models
2) Rapid 1D thermal system models

**Why?**

1) Characterize thermal duty cycles
2) Evaluate breakthrough technologies and design tradeoffs
Uniqueness of Project and Impacts

Advanced Vehicle Systems

APEEM Technology Development

APEEM Thermal Control Subsystem integration, performance, requirements

Potential Thermal Control Technologies

Jet Cooling  Spray Cooling  TIM  Low R Structure  Phase Alternative Change Coolants  Air Cooling  Surface Enhancements

Systems context pulls all aspects of thermal control together.
Accomplishments to Date

Characterize Thermal Duty Cycle

1) Evaluated thermal duty cycle for 2004 Prius motor inverter (DOE Milestone).

2) Performed preliminary analysis of PHEV requirement impacts on PEEM systems to quantify thermal control implications.

Evaluate Breakthrough Technologies

1) Initiated methodology for rapid 1D thermal models to support PE package design and thermal reliability.

2) Developed parametric FEA thermal model to evaluate performance of advanced inverter cooling concepts (2007 IEEE VPPC).

- Packages: TIM, Integrated Heat Sink, Direct Backside Cooling, Double Sided.
- Thermal: Fins, Jet Impingement, Air, TIM, Coolant Temperatures, Junction Temperatures.
Project Objective for FY08

- Integrate thermal control technologies into commercially viable systems.

  - What are feasible system design directions?
  - What analysis tools can speed up R&D evaluations prior to hardware builds?
  - How close are breakthrough technologies?

Deliverables

1) Develop rapid transient thermal models for power electronics.

2) Evaluate power electronics thermal control and packaging tradeoffs.
Technical Approach for FY08

1) Rapid Power Electronics Transient Thermal Model

- Develop methodology and tools integrating transient thermal simulations with dynamic electrical and vehicle systems models.

Why?

1) Characterize thermal duty cycles.
2) Evaluate breakthrough technologies and design tradeoffs.
Technical Approach for FY08

1) Rapid Power Electronics Transient Thermal Model

1. Model development in a flexible programming environment
2. Parameter identification techniques
3. FEA model verification
4. Hardware validation
5. Integration with component R&D efforts (ORNL & NREL)
6. Integration with reliability tools to determine critical stress loads over “real” operating conditions
Technical Approach for FY08

2) Power Electronics Thermal Control and Packaging Tradeoffs

- Evaluate advanced packaging and cooling technologies:
  - Performance
  - Volume
  - Thermal time constant

Why?

1) Characterize thermal duty cycles
2) Evaluate breakthrough technologies and design tradeoffs
Technical Approach for FY08

2) Power Electronics Thermal Control and Packaging Tradeoffs

1. Refine parametric 3D FEA model to minimize package volumes.
2. Quantify volume impacts of package designs.
3. Quantify transient response impacts of package designs.
4. Hardware validation.
Timeline

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Event</th>
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<tbody>
<tr>
<td>2007</td>
<td>Oct</td>
<td>Rapid Model Development</td>
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<tr>
<td></td>
<td>Nov</td>
<td>ORNL PE Thermal Design Support</td>
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<td></td>
<td>Dec</td>
<td>Rapid Model Validation</td>
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<td>2008</td>
<td>Jan</td>
<td>Quantify Transient and Volume Impacts of Package Designs</td>
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<td></td>
<td>Feb</td>
<td>Validate Transient and Volume Impacts</td>
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<td></td>
<td>Mar</td>
<td>Year End Report</td>
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Thermal Systems Reliability
The Challenges/Barriers

- Commercially viable thermal control technologies must minimize the overall system complexity, cost, volume, and weight while maintaining performance and reliability.

![Graph showing cost vs. cumulative production.]

2020 Cost Target = $8/kW peak
Beyond FY08

Thermal Systems Objective

Measure impact of breakthrough thermal control technologies and provide R&D direction.

• FY09
  – Evaluate cost and parasitic power tradeoffs for PE cooling technologies
  – Integrate thermal control of EM