Heavy Duty Powertrain System Optimization and Emissions Test Procedure Development

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Project ID: VSS108

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Overview

Timeline
- Start – FY12
- Finish – FY14
- 60% complete

Barriers
- Risk aversion
- Cost
- Lack of standardized test protocols
- Constant advances in technology

Budget
- Total project funding
  - DOE share – 64%
  - Cost share – 36%
- Funding for FY12: $1,750K
- Funding for FY13: $1,300K

Partners
- Meritor
- Cummins
- Environmental Protection Agency (EPA)
- International Council on Clean Transportation (ICCT)
- Eaton
Project Objectives

- **Overall Objective**
  - Provide expertise and test facilities for heavy duty advanced powertrain systems research, development, and integration

- **FY13 Objectives**
  - Establish the ORNL Vehicle Systems Integration (VSI) laboratory to support DOE VT Hybrid Electric Systems suited to characterize component behaviors exposed to real-world operating conditions in a vehicle systems context, or subsystem interactions based on various advanced powertrain architectures.
  - Support:
    - Phase 2 of the EPA Green House Gas (GHG) rulemaking
    - SAE J2711 (Medium and Heavy Duty “x”-in-the-loop test procedures)
  - Collaborate with industry for advanced Class 8 hybrid powertrain control strategy development and experimental powertrain verification
<table>
<thead>
<tr>
<th>Date</th>
<th>Milestones and Go/No-Go Decisions</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sept-2012</td>
<td><strong>Milestone:</strong> Procure dynamometers for VSI powertrain test cell</td>
<td>Complete</td>
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<tr>
<td>April-2013</td>
<td><strong>Milestone:</strong> Commission VSI powertrain test cell complete with battery emulator</td>
<td>On Track</td>
</tr>
<tr>
<td>April-2013</td>
<td><strong>Milestone:</strong> Kick-off WFO for EPA phase 2 GHG rule making test procedure development</td>
<td>On Track</td>
</tr>
<tr>
<td>Sept-2013</td>
<td><strong>Milestone:</strong> Complete evaluation of prototype class 8 heavy hybrid powertrain</td>
<td>On Track</td>
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</table>
Establish the ORNL Vehicle Systems Integration (VSI) laboratory

- Procure and commission powertrain dynamometer test system suitable for class 8 truck hybrid powertrain transient testing
- Procure and commission high power battery emulator suitable for class 8 truck hybrid powertrain transient testing
- Integrate dynamometers and battery emulator with hardware-in-the-loop system to emulate virtual vehicle platforms and drive cycles
Approach/Strategy

• Develop test standards/procedures to support Phase 2 of the EPA GHG rulemaking
  – Powertrain systems commissioning
  – Hardware-in-the-loop software development and validation
  – Powertrain configurations testing
  – Correlation with chassis testing results

• Support SAE J2711 (medium and heavy duty “x”-in-the-loop test procedures)
Approach/Strategy

• Develop and validate advanced Class 8 hybrid powertrain control strategies:
  – Commission Meritor hybrid powertrain on VSI powertrain test cell
  – Refine control strategies
  – Benchmark fuel economy and emissions against conventional powertrain over pre-determined drive cycles

• Model validation and enhancement based upon experimental results
**Technical Accomplishments**  
**Dyno Procurement and Commissioning**

- Procured 2 AVL 500kW dynos
- Completed dyno commissioning
- Commissioned Cummins ISX 450 engine on single-ended dyno:
  - Performed steady-state engine mapping and transient operation characterization
  - Established torque and injection control over J1939 suitable for hybrid operation (stop/start)

![Dyno Image]
Technical Accomplishments

Battery Emulator Procurement

• Procured 400kW battery emulator
• Delivered and installed in VSI lab in March 2013
• To be commissioned in May
• Provides service to both VSI powertrain test cell and component test cell.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Capacity</td>
<td>400kW</td>
</tr>
<tr>
<td>Input characteristics (mains)</td>
<td></td>
</tr>
<tr>
<td>Power consumption</td>
<td>444.4kVA</td>
</tr>
<tr>
<td>Input voltage</td>
<td>480 ± 10% VAC, 3-phase, PE</td>
</tr>
<tr>
<td>Input frequency</td>
<td>60 ± 5% Hz</td>
</tr>
<tr>
<td>Input current</td>
<td>max. 620A</td>
</tr>
<tr>
<td>Power factor</td>
<td>&gt; 0.99 from 10% load</td>
</tr>
<tr>
<td>Inrush current</td>
<td>&lt; I_{rated}</td>
</tr>
<tr>
<td>Output characteristics (unit under test)</td>
<td></td>
</tr>
<tr>
<td>Output voltage</td>
<td>8-800 VDC</td>
</tr>
<tr>
<td>Feedback DC voltage</td>
<td>10-800 VDC</td>
</tr>
<tr>
<td>Output current</td>
<td>± / - 600A (note max. capacity output rating)</td>
</tr>
<tr>
<td>AVL Battery Simulator™ control unit</td>
<td>included</td>
</tr>
</tbody>
</table>
Technical Accomplishments

Hardware-In-the-Loop Commissioning

- Interfaced hardware-in-the-loop real-time computer with dyno controller
- Modified Autonomie vehicle models for HIL bypass
- Commissioned engine-in-the-loop configuration:
  - Conventional powertrain
  - Hybrid powertrain
Technical Accomplishments
Support of EPA GHG rulemaking

• Defined statement of work to support Phase 2 of the EPA GHG rulemaking in collaboration with:
  – EPA
  – ICCT
  – Cummins

• Procured Eaton UltraShift® automated manual transmission for conventional powertrain-in-the-loop configuration

• Modified HIL system to be suitable for three testing modes:
  – Vehicle Cycle (Vehicle Speed and Road Grade vs. Time)
  – Powertrain Cycle (Normalized Powertrain Speed and Normalized Powertrain Torque vs. Time)
  – Generic Vehicle Cycle (Vehicle Speed and Residual Power vs. Time)
Technical Accomplishments
Class 8 Hybrid Powertrain Evaluation

• Tested engine-in-the-loop configuration of Meritor DMHP:
  – Actual ISX engine running in VSI test cell
  – Virtual DMHP and vehicle models computed on real-time platform

• Prepared installation of Meritor DMHP on VSI powertrain test cell:
  – Technology transfer meeting held in December at Meritor
  – Weekly web meetings to:
    • Coordinate ORNL and Meritor activities
    • Resolve test cell integration issues
### Collaboration and Coordination

<table>
<thead>
<tr>
<th>Organization</th>
<th>Type of Collaboration/Coordination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meritor</td>
<td>Supply Dual Mode Hybrid Powertrain (DMHP) transmission CRADA partner</td>
</tr>
<tr>
<td>Environmental Protection Agency (EPA)</td>
<td>Sponsor Phase 2 of the GHG rulemaking</td>
</tr>
<tr>
<td>International Council on Clean Transportation (ICCT)</td>
<td>Support powertrain-in-the-loop testing</td>
</tr>
<tr>
<td>Cummins</td>
<td>Support powertrain-in-the-loop testing Engineering support for ISX450 engine</td>
</tr>
<tr>
<td>Eaton</td>
<td>Support Powertrain in the loop testing Supply AMT transmission and engineering support</td>
</tr>
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Proposed Future Work

• Remainder of FY13
  – Complete commissioning of class 8 hybrid powertrain configuration (dual dyno and battery emulator)
  – Commission Meritor hybrid transmission, refine and validate control strategies
  – Support Phase 2 of the EPA GHG rulemaking
    • Test specified X-in-the-loop configurations

• FY14
  – Complete X-in-the-loop testing for EPA
Summary

• Relevance
  – Validate, in a systems context, performance targets for deliverables from the Power Electronics and Energy Storage Technology R&D activities.
  – Address codes and standards needed to enable wide-spread adoption of electric-drive transportation technologies

• Approach
  – Establish the ORNL Vehicle Systems Integration (VSI) laboratory
  – Support Phase 2 of the EPA GHG rulemaking
  – Develop and validate advanced Class 8 hybrid powertrain control strategies

• Technical accomplishments and progress
  – Procured dynamometers, battery emulator and HIL platform
  – Commissioned engine-in-the-loop configurations (conventional and hybrid virtual powertrain)
  – Established working relationships and paperwork to support phase 2 of the EPA GHG rulemaking

• Collaborations:
  – EPA, Cummins, Meritor, ICCT, Eaton

• Proposed Future Work
  – Commission dual dyno configuration and battery emulator
  – Commission conventional and hybrid class 8 powertrain
  – Perform testing to support phase 2 of the EPA GHG rulemaking