

Heavy Duty Powertrain System Optimization and Emissions Test Procedure Development

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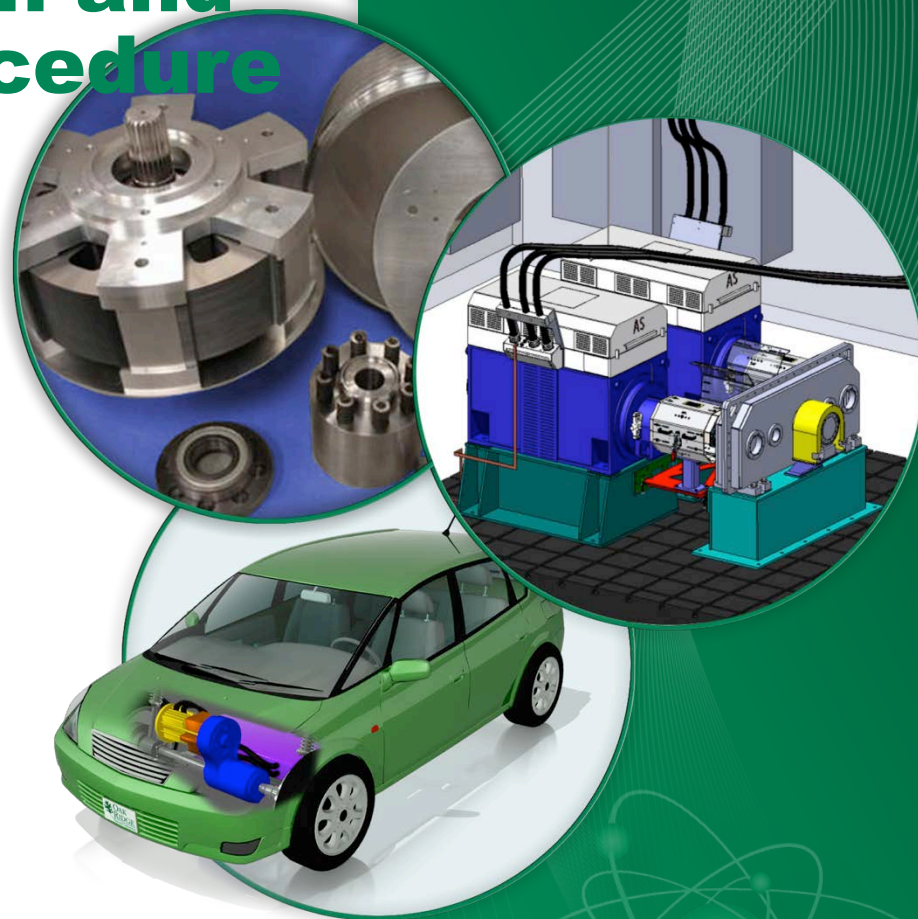
Oak Ridge National Laboratory

2013 U.S. DOE Hydrogen and Fuel Cells Program and Vehicle Technologies Program Annual Merit Review and Peer Evaluation Meeting

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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**

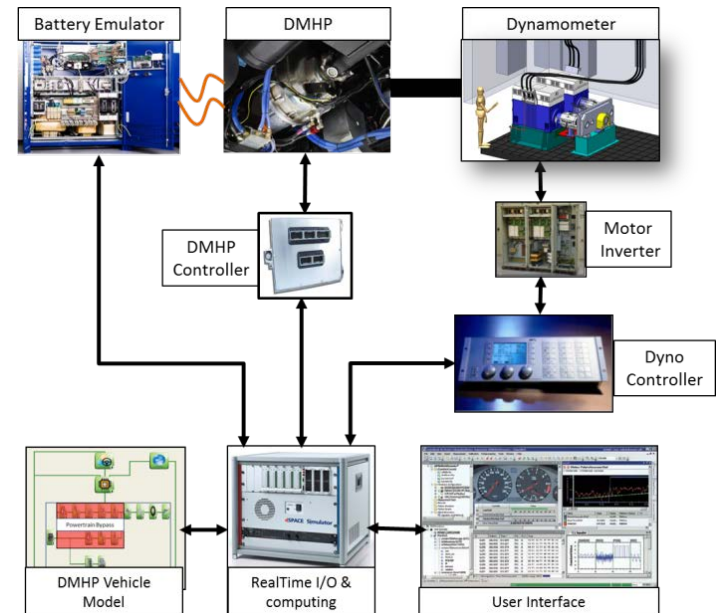
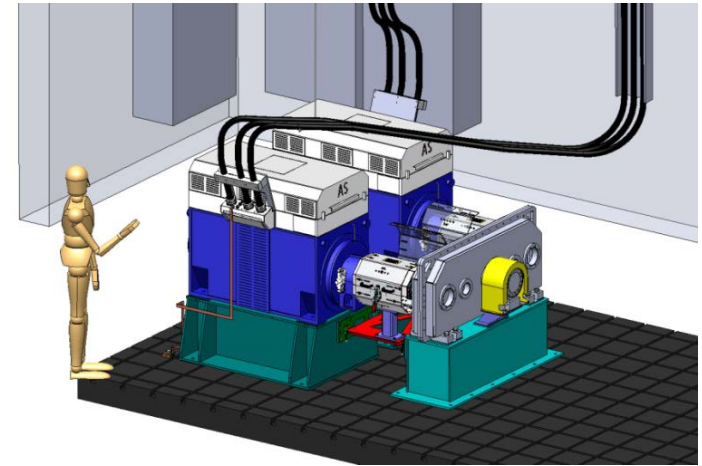
- Establish the ORNL Vehicle Systems Integration (VSI) laboratory to support DOE VT Hybrid Electric Systems suited to characterize component behaviors exposed to real-world operating conditions in a vehicle systems context, or subsystem interactions based on various advanced powertrain architectures.
- 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

Milestones

Date	Milestones and Go/No-Go Decisions	Status
Sept-2012	<u>Milestone</u> : Procure dynamometers for VSI powertrain test cell	Complete
April-2013	<u>Milestone</u> : Commission VSI powertrain test cell complete with battery emulator	On Track
April 2013	<u>Milestone</u> : Kick-off WFO for EPA phase 2 GHG rule making test procedure development	On Track
Sept 2013	<u>Milestone</u> : Complete evaluation of prototype class 8 heavy hybrid powertrain	On Track

Approach/Strategy

- 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



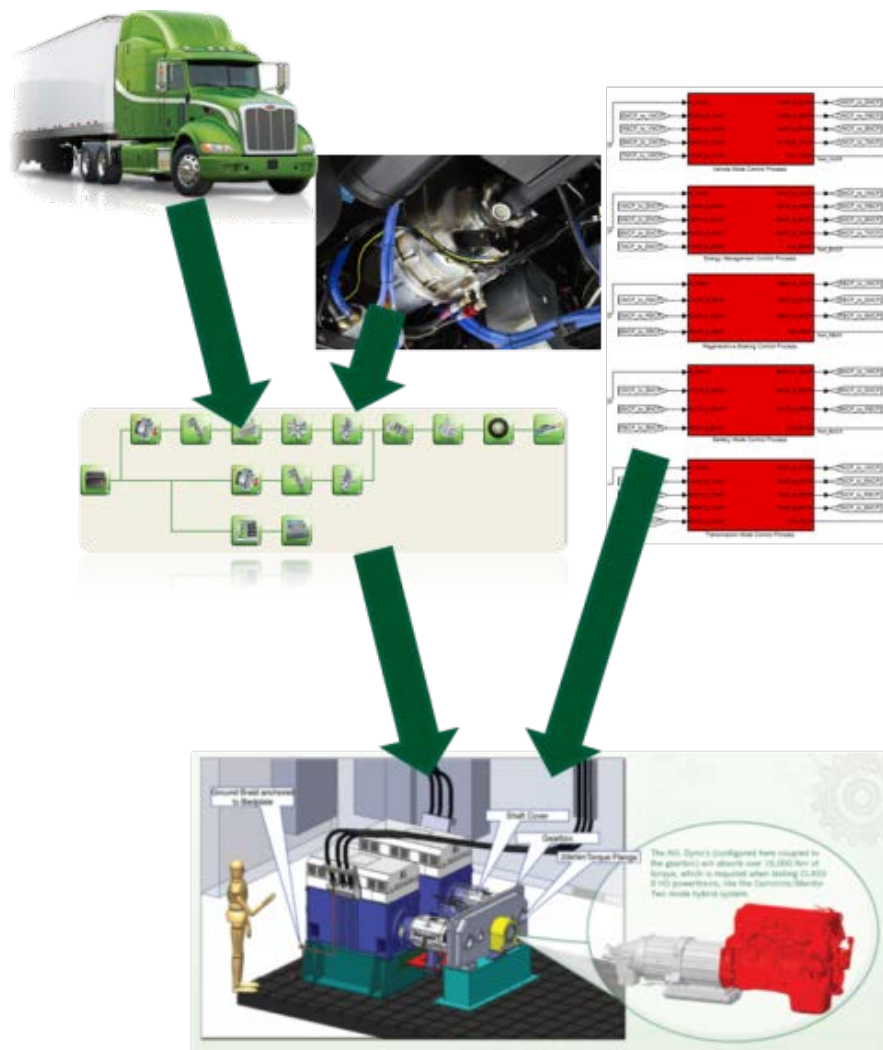
Approach/Strategy

- 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

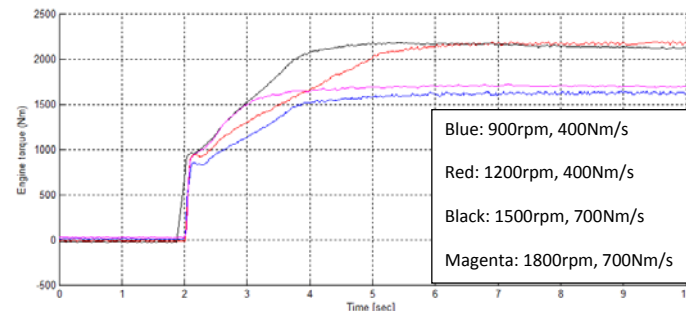
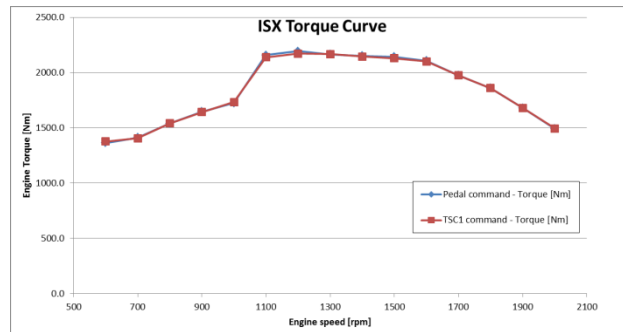
- Develop and validate advanced Class 8 hybrid powertrain control strategies:
 - Commission Meritor hybrid powertrain on VSI powertrain test cell
 - Refine control strategies
 - Benchmark fuel economy and emissions against conventional powertrain over pre-determined drive cycles
- Model validation and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



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.



Nominal Capacity:	400kW
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Input characteristics (mains)	
Power consumption:	444,4kVA
Input voltage:	480 \pm 10% VAC, 3-phase, PE
Input frequency:	60 \pm 5% Hz
Input current:	max. 620A
Power factor:	> 0,99 from 10% load
Inrush current:	< I _{Rated}

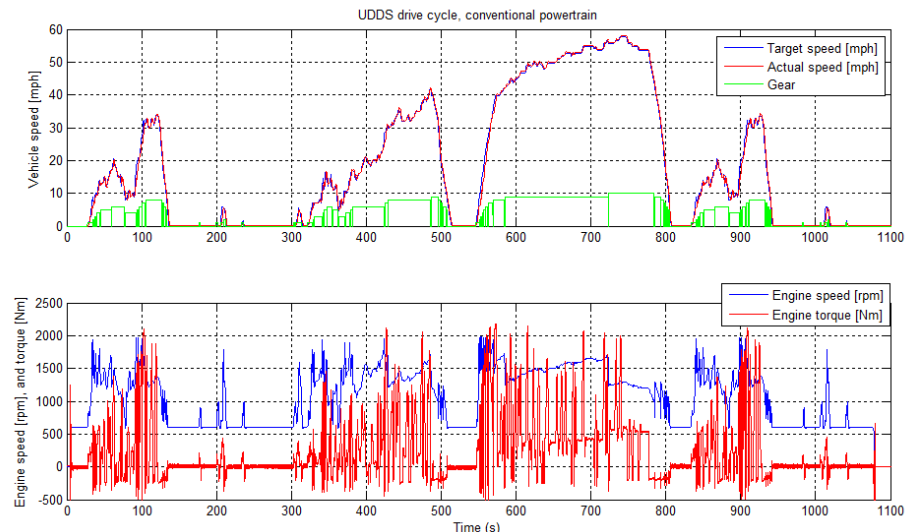
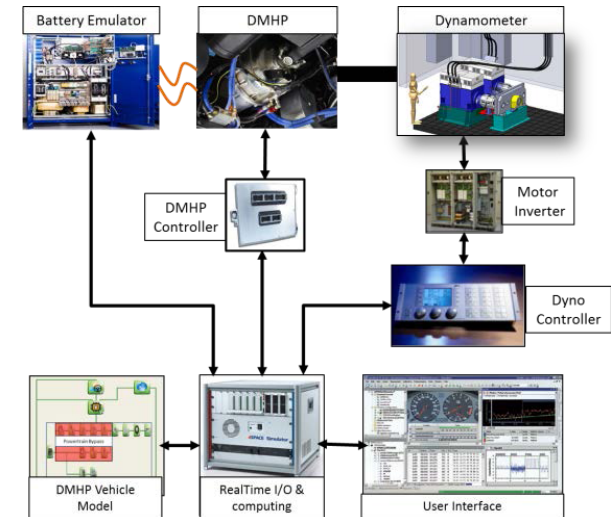
Output characteristics (unit under test)	
Output voltage:	8-800 VDC
Feedback DC voltage:	10-800 VDC
Output current:	+ / - 600A (note max. capacity output rating)

AVL Battery Simulator™ control unit	included
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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

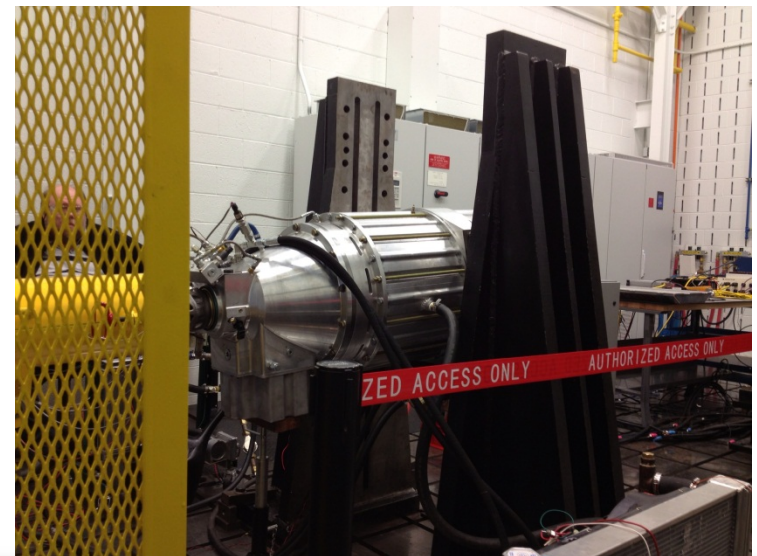
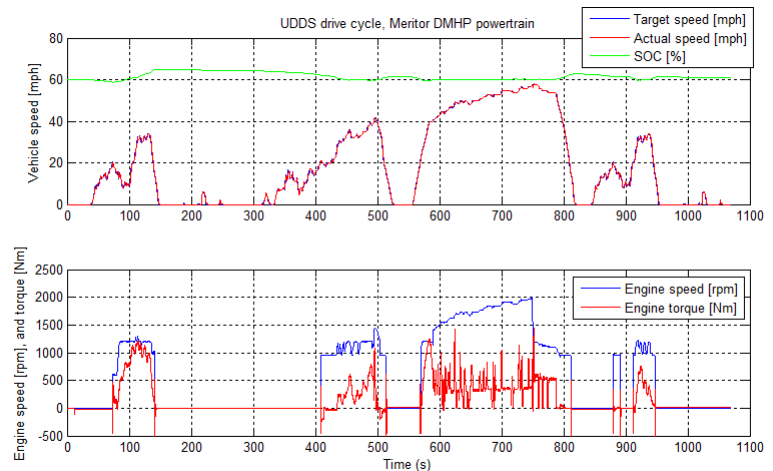
- Defined statement of work to support Phase 2 of the EPA GHG rulemaking in collaboration with:
 - EPA
 - ICCT
 - Cummins
- Procured Eaton UltraShift® automated manual transmission for conventional powertrain-in-the-loop configuration
- Modified HIL system to be suitable for three testing modes:
 - Vehicle 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

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

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