PHEV Engine Control and Energy Management Strategy

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VSS013

Overview

- **Timeline**
  - Project start date: Oct. 2009
  - Project end date: Sept. 2012
  - 10% complete
- **Barriers**
  - Engine control for fast engine and catalyst warm-up
  - Hybrid control for optimized powertrain emissions
  - Lack of access to production engine control system
- **Budget**
  - New project, no FY09 funding
  - FY10 (current) funding: $400k
  - FY11 (projected) funding: $400k
  - FY12 (projected) funding: $300k
- **Partners**
  - Oak Ridge National Laboratory
  - The University of Tennessee, Knoxville
  - Argonne National Laboratory

Objectives

- Investigate novel engine control strategies targeted at rapid engine/catalyst warming for the purpose of mitigating tailpipe emissions from plug-in hybrid electric vehicles (PHEV) exposed to multiple engine cold start events.
- Implement engine control algorithms into an experimental test stand engine hardware-in-the-loop in order to validate control methodologies and verify transient thermal and emissions performance.
- Supervisory control techniques developed during other previous and on-going research projects will be integrated into the vehicle level control system along with the modified engine control strategies for emissions reduction during both cold start and engine re-starts.

Relevance

- **VTP Multi-Year Program Plan**
  - **By 2015, improve the fuel economy of light-duty gasoline vehicles by 25 percent and of light-duty diesel vehicles by 40 percent, compared to the baseline 2009 gasoline vehicle with Tier 2, Bin 2 emissions levels (Advanced Combustion R&D/Combustion and Emissions Control R&D technical target form MYPP)**
- **Barriers**
  - **Engine control for fast engine and catalyst warm-up**
    - **Project will develop novel engine control strategies for fast engine and catalyst warm-up**
  - **Hybrid control for optimized powertrain emissions**
    - **Project will integrate novel hybrid control strategies to co-ordinate engine and motor operation to reduce overall powertrain emissions**
  - **Lack of access to production engine control system**
    - **Project will develop an open source prototype engine controller so that engine control strategies are fully customizable**

Milestones

- **Milestone #1, September 30, 2010 :**
  - **Select and characterize OEM calibration for candidate engine**

- **Milestone #2, September 30, 2010 :**
  - **Develop and implement baseline engine control strategy for open source hardware**

Approach (Phase 1, FY2010)

- **Engine selection**
  - **Choose modern engine technology to be used in foreseeable future**
  - **Choose relevant engine size for hybrid applications**
- **Engine characterization (Milestone #1)**
  - **Establish OEM-calibration:**
    - **Performance**
    - **Fuel consumption**
    - **Emissions**
  - **Characterize sensors and actuators**
- **Open source prototype engine controller development (Milestone #2)**
  - **Define prototype controller hardware and software architecture**
  - **Develop engine control strategies for target engine**
  - **Adapt controller for specific sensors and actuators and baseline calibration**
  - **Commission controller on dyno cell**
  - **Tune calibration and strategies so that engine operates as closely as possible in terms of emissions and performance to the OEM calibration.**

Approach (Phase 2, FY2011)

- **Hardware-In-the-Loop System Preparation and Development**
  - **Select PHEV powertrain architecture based on current trends and on-going research at national laboratories**
  - **Develop complete Autonomie vehicle level model**
  - **Implement powertrain and vehicle model on Hardware-In-the-Loop system**
  - **Commission Hardware-In-the-Loop system on dynamometer test cell and integrate with actual engine and controller (Engine-In-the-Loop configuration: real engine coupled to virtual powertrain and vehicle)**
- **Engine control strategies development and calibration with focus on:**
  - **Engine warm-up**
  - **Rapid catalyst heating**
  - **Reduced cold emissions (with limited regards for minimizing fuel consumption)**
- **Engine control strategies implementation and validation on dynamometer**
  - **Use prototype controller to implement modified engine control strategies**
  - **Test and calibrate engine control strategies on dynamometer test cell to minimize emissions and speed up catalyst heating**
- **Supervisory hybrid vehicle control integration**
  - **Integrate strategies developed as part of ORNL FY2010 AOP Task 3.0c: PHEV Emissions and control strategy with engine control strategies developed so far (simulation first)**
  - **Test the integrated solution on an Engine-In-the-Loop test platform**

Approach (Phase 3, FY2012)

- Hybrid and Engine control strategies integration and calibration
- Optimization to focus on reducing both
  - Cold start emissions AND
  - Fuel consumption
- Extensive iterative testing to identify correct trade-offs between emissions and fuel consumption

Accomplishments – Administration and Procurement

- Recruitment of new research engineer to work on project (Dec. 2009)
- Sub- contract initiation with The University of Tennessee Knoxville (UTK) (Jan. 2009) for :
  - Testing facilities (engine dynamometer and Hardware-In-the-Loop system)
  - Testing and Engineering manpower
  - Dr. Irick and UTK's Engine and Emissions Expertise
- Control system and simulation tools procurement (Jan. 2009)
  - WoodWard's Mototron Control Solution (RealTime Software and Hardware prototype control strategies development tools)
  - Matlab and Simulink (modeling environment)
  - Autonomie (vehicle and powertrain models)
- Co-operation discussions with two American OEMs (Jan-Mar. 2009)
  - Requests for engineering support during engine characterization phase on dynamometer cell
  - Unsuccessful attempts because of OEM's lack of resources

Accomplishments – Engine Selection

- **Engine selection criteria:**
  - Size and power suitable for PHEV application
  - Gasoline direct injection for added degree of freedom to reduce emissions
  - Naturally aspirated for simplicity
  - Commonality with other ORNL engine projects
  - Ease of replacement of OEM ECU with prototype controller
- **GM Ecotec LAF engine specifications**
  - Gasoline Direct Injection
  - Naturally aspirated (VVT, no EGR, no turbo)
  - 2.4l, 4 cylinder
  - 182 hp (136 kW) @ 6700 rpm
  - 172 lb.ft (233 Nm) @ 4900 rpm (gasoline)
  - Available in 2010 GMC Terrain, Chevrolet Equinox and Buick LaCrosse
- **Other considerations**
  - Ecotec LNF (2.0l GTDI) variants used on two projects at ORNL
  - Past experience with replacing LNF ECU with Woodward prototype controller

Accomplishments – Engine Characterization Planning

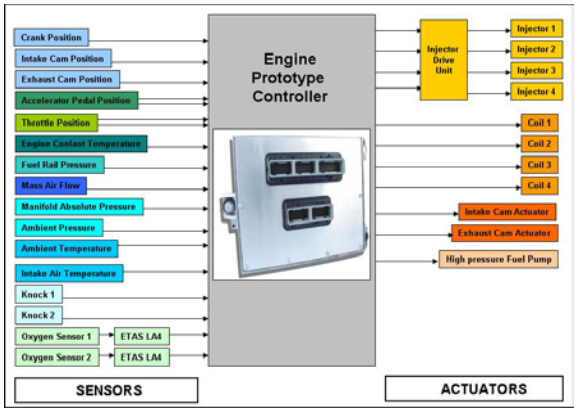
- **Original plan (with OEM support)**
  - **Engine characterization on Dynamometer cell**
  - **Assumes OEM co-operation to provide "dyno" Engine Control Unit (controller with special calibration to ignore fault codes and prevent abnormal operation due to absence of vehicle signals when engine is tested as a stand alone component on a dynamometer test stand)**
  - **Cannot be done without OEM approval and support**

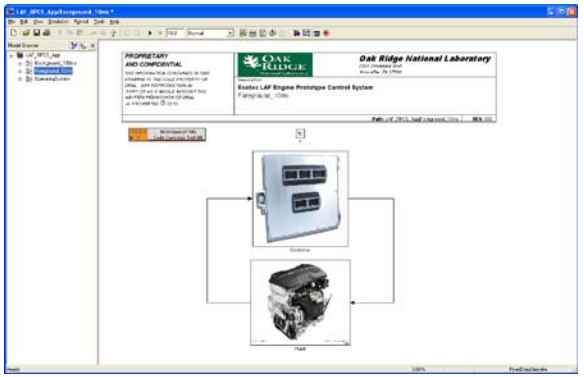
- **Revised plan (without OEM support)**
  - **Engine characterization in a vehicle on chassis rolls**
  - **Simple work-around to guarantee normal engine operation and therefore representative characterization and reverse engineering**
  - **Vehicle testing implies driveline efficiency assumptions for engine characterization (to be validated later on when open source controller is in place)**
  - **Vehicle rental and instrumentation preparation in progress**

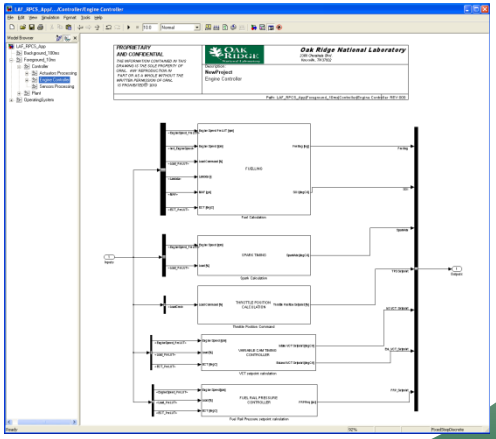
Accomplishments – Prototype Engine Controller Development

- **Hardware Selection**
  - Engine Controller: Woodward ECM-565-128
  - Injector Drive Unit for high pressure injector to be finalized after engine characterization
  - Harness design to be completed after engine characterization

- **Software architecture**
  - Woodward Motohawk tool suite
  - Mathworks Matlab/Simulink/RTW tool suite
  - Implementation of Simulink-based gasoline control strategies
  - Simple look-up table based strategies for engine commissioning
  - Later addition of cold start and catalyst heating features







Collaboration and Coordination with Other Institutions

- **Partners**
  - **Oak Ridge National Laboratory (lead)**
    - **Control systems development (hardware and software)**
  - **The University of Tennessee Knoxville (sub-contractor)**
    - **DOE Graduate Automotive Technology Education (GATE) center concentrated on hybrid powertrains and control systems.**
    - **Testing performed at UTK's Advanced Powertrain Controls and System Integration (APCSI) facility**
    - **Training graduate students in some of the unique aspects of advanced powertrain control development.**
  - **Argonne National Laboratory**
    - **Strategies development in off line environment (VSS012: Tradeoff between Fuel Consumption and Emissions for PHEV's)**
    - **Strategies will be tested and refined on engine dynamometer cell**

Proposed Future Work

- **FY10**
  - **Engine characterization (Milestone #1, September 30, 2010)**
  - **Open source prototype engine controller development (Milestone #2, September 30, 2010)**

- **FY11**
  - **Hardware-in-the-loop preparation and development**
  - **Engine control strategies development and calibration**
  - **Engine control strategies implementation and validation on dynamometer**
  - **Supervisory hybrid vehicle control integration**

Summary

- **Slow project ramp-up due to**
  - **Resources constraints**
  - **Delays while investigating OEM's interest and availability to support**
  - **OEMs declined to support because of lack of resources**

- **Testing plan revised accordingly and progressing well**
  - **Suitable engineering resources**
  - **Control system equipment procurement completed**
  - **Engine selection completed**
  - **On-going engine procurement**
  - **On-going control strategies development for open source controller**

Acknowledgements and Contacts

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ORNL Investigators:

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