PHEV Engine Control and Energy Management Strategy

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Overview

• Timeline
  – Project start date: Oct. 2009
  – Project end date: Sept. 2012
  – 30% complete

• Barriers
  – Cold start PHEV emissions

• Budget
  – FY10 (current) funding: $400k
  – FY11 (projected) funding: $350k
  – FY12 (projected) funding: $350k

• Partners
  – Oak Ridge National Laboratory, project lead
  – The University of Tennessee (UT), Knoxville, GATE center
  – Argonne National Laboratory, Autonomie Series hybrid model and PHEV emissions study
  – Robert Bosch LLC, production controller supply and support
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.
- Optimize integration of engine control strategies with hybrid supervisory control strategies in order to reduce cold start emissions and fuel consumption of PHEVs.
- Ensure that development of new vehicle technologies complies with existing emission standards

Relevance with regards to VT programs

- Demonstrate market readiness of grid-connected vehicle technologies by 2015
- Develop advanced control strategies to optimize the performance and efficiency of advanced hybrid electric vehicle
- Complete the successful deployment of Autonomie as an industry recognized advanced component and vehicle modeling and simulation tool.
Approach

- **Gain full control over stand-alone engine operation in test cell**
  - Characterize engine performance, emissions and operation
  - Develop open source prototype engine controller
  - Commission controller on UT test cell

- **Optimize engine cold start strategies on stand-alone engine**
  - Implement best in class engine control strategies in open source controller
  - Improve/optimize strategies to reduce cold start emissions

- **Engine-In-the-Loop (EIL) system testing**
  - Leverage Autonomie PHEV model
  - Develop EIL platform suitable for PHEV emulation
  - Port Autonomie model into EIL platform
  - Commission and validate EIL system

- **Optimize hybrid supervisory strategies and engine control strategies as a system in order to reduce tailpipes emissions on the EIL test stand**
  - Integrate and improve hybrid supervisory control strategies from ANL-ORNL simulation study (“Trade-off between fuel economy and Emissions for PHEVs”)
  - Concurrently optimize both control strategies (engine and hybrid) as a system
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

- **Milestone #3, March 31, 2011:**
  - Set-up and parameterize an Engine-In-the-Loop (EIL) system to represent hybrid powertrain and vehicle.

- **Milestone #4, June 30, 2011:**
  - Develop and implement new engine control strategies on open source hardware focusing on improving catalyst heating and cold engine emissions

- **Milestone #5, September 31, 2011:**
  - Integrate supervisory hybrid control strategies with engine control strategies on engine dynamometer stand with HIL system and optimize cold emissions without consideration for fuel consumption
Accomplishments – Base Engine Characterization

- **Procurement of 2011MY Equinox LT** (vehicle equipped with 2.4l LAF Ecotec® engine previously selected for this project)
- **Vehicle/engine instrumentation**
- **Engine characterization on ORNL chassis rolls facilities at NTRC**
  - Engine out and tailpipe emissions
  - Performance and fuel economy
  - Engine base operations
  - Sensors and actuators transfer functions
- This completes Milestone #1.
- This data is critical to the development of our open source controller.
Accomplishments – Stand-alone engine operation in test cell with open source controller

- Open source controller development
  - Existing baseline strategies refinement
  - Customization with previously characterized engine operation data
  - Implementation into production-intent module

- Test cell commissioning
  - Test cell located at UTK's Advanced Powertrain Controls and System Integration (APCSI) facility.
  - First engine to be run at this new facility
  - Facilities enhancement were required

- Engine commissioning
  - Engine installation
  - Control system debugging and tuning

- Engine mapping

- This completes Milestone #2.

- Unique controller provides full flexibility over engine operation including cold start behavior
Accomplishments – Vehicle Simulation

- Leverage ANL/ORNL collaboration project (Tradeoff between Fuel Consumption and Emissions for PHEV's) whose focus is on Hybrid supervisory strategies optimization (Engine is a “black box” that can not be modified)

- Addition of a new team member: Andreas Malikopoulos, ORNL Weinberg fellow, to support simulation study and optimization phase

- Series hybrid powertrain simulation

- Reduced emissions through pre-warming and torque shaping come with a fuel economy penalty

- This simulation study provides vehicle and powertrain models for Hardware-In-the-Loop study
Accomplishments – Engine-In-the-Loop Setup

- Hardware-In-the-Loop platform set-up
- Integration of Autonomie vehicle model onto real time platform
- This set-up enables the evaluation of an actual engine behavior for a specific vehicle configuration providing:
  - Real emissions measurements
  - Flexibility to change powertrain configurations and test conditions
Accomplishments – Engine Cold Start Strategies

- Literature search about gasoline direct-injected engine cold start and catalyst warm-up strategies.

- Strategies implemented into open source controller

- Strategies to combine:
  - Stratified cranking
  - Retarded ignition
  - Split Homogenous-Stratified injections
  - AFR optimization
  - High fuel pressure
  - Exhaust VVT retard

- Kukwon Cho from ORNL FEERC (Fuel Engine and Emissions Research Center) group will support that task and bring more engine experience to the project team

- Cold start strategies will be evaluated on open source controller and stand-alone engine in UT test cell
Accomplishments – Industry Partnership

- Advanced discussions with Robert Bosch LLC (Bosch) to collaborate on this project: NDA and CRADA initiated and progressing

- Bosch will supply:
  - Engine controller for GM 2.0l GTDI LNF engine
  - Access to cold start calibration and bypass.

- ORNL will supply facilities, engine and engineering resources

- Benefits:
  - Use of production engine controller. No need to “re-invent the wheel” developing base control strategies. Effort can be focused on cold starts.
  - Access to production calibration (with GM’s approval).
  - Bypass features allow to keep all production strategies except for area of interest: cold starts
  - Guidance from Major Tier1 supplier
  - LAF engine and open source controller still available for testing and strategies validation on this project and subsequent projects
Collaboration and Coordination with Other Institutions

- **Oak Ridge National Laboratory**
  - Lead
  - Control systems development
  - Emissions and after-treatment expertise (FEERC)

- **The University of Tennessee Knoxville**
  - 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 (two students working on this project)

- **Argonne National Laboratory**
  - Hybrid supervisory strategies optimization study (This project draws from a collaborative project between ANL and ORNL: Tradeoff between Fuel Consumption and Emissions for PHEV’s).

- **Bosch**
  - Supply of development engine ECU and production calibration (with GM’s approval)
  - Support to set up engine control system
Proposed Future Work

- **FY11**
  - Engine-In-the-Loop commissioning at UT’s APCI lab
  - Engine cold start strategies test and refinement on engine stand-alone setup
  - Supervisory control strategies implementation and development on EIL platform.
  - Commission LNF 2.0l GTDI engine and Bosch bypass control system in testcell
  - Implement new cold start strategies on Bosch bypass control system

- **FY12**
  - Iterative concurrent emissions optimization of engine control strategies and hybrid supervisory strategies
  - System optimization with fuel economy as an additional constraint

- **FY13 (Tentative extension)**
  - Bosch CRADA
  - HC trap investigation
Summary

- Established open source prototype engine controller running stand-alone engine operation in UT test cell
- Designed Engine-In-the-Loop platform
- Established PHEV Autonomie vehicle level model
- Implemented engine cold start strategies on open source controller
- Established relationship with Tier 1 supplier Bosch to supply production engine controller.
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