Electric Drive Vehicle Level Control Development Under Various Thermal Conditions

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Sponsored by Lee Slezak

Project ID #VSS070

Project Overview

Timeline

- Start – September 2011
- End – September 2012
- 70% Complete

Budget

- FY12
  - $150K (HEV)
  - $100K (PHEV)

Barriers

- Implement detailed component thermal model
- Assess impact of temperature on fuel displacement

Partnership

- Automotive manufacturer
- Battery manufacturer
- MathWorks
- Argonne APRF
- NREL

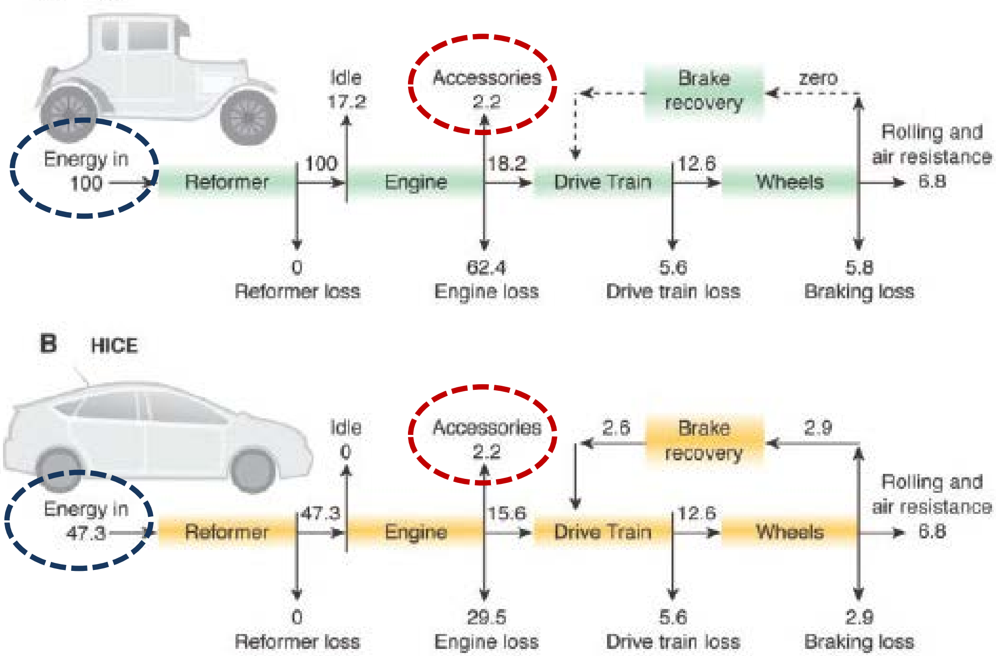
Relevance

The objective is to develop the entire vehicle thermal management system for two electric drive vehicles (HEVs, PHEVs).

- Limited battery power and low engine efficiency at cold temperature results in low fuel economy, shorter range and high emissions.
- Vehicle thermal management system (VTMS) model and the vehicle powertrain model are integrated to predict thermal response of the VTMS and fuel economy of the vehicle under various vehicle thermal and driving conditions.
- Validated model will be used to analyze and improve the performance of the VTMS and its fuel economy.

Relevance

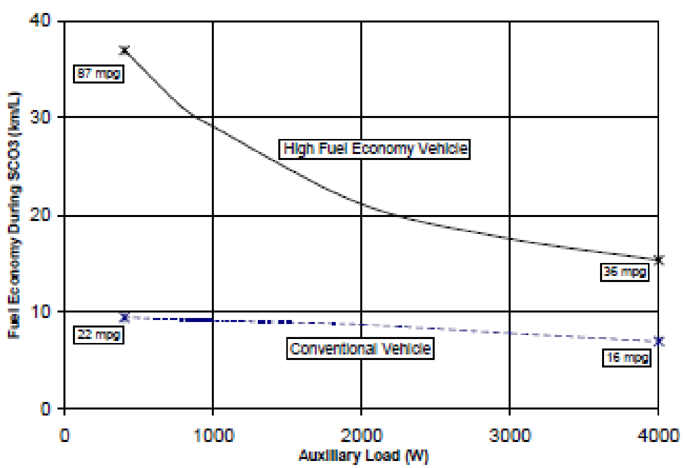
Energy flow for conv. and parallel HEV configurations (“*Hybrid Cars Now, Fuel Cell Cars Later*”, Science)



- A high fuel economy vehicle is more affected by the auxiliary load than a conventional vehicle.

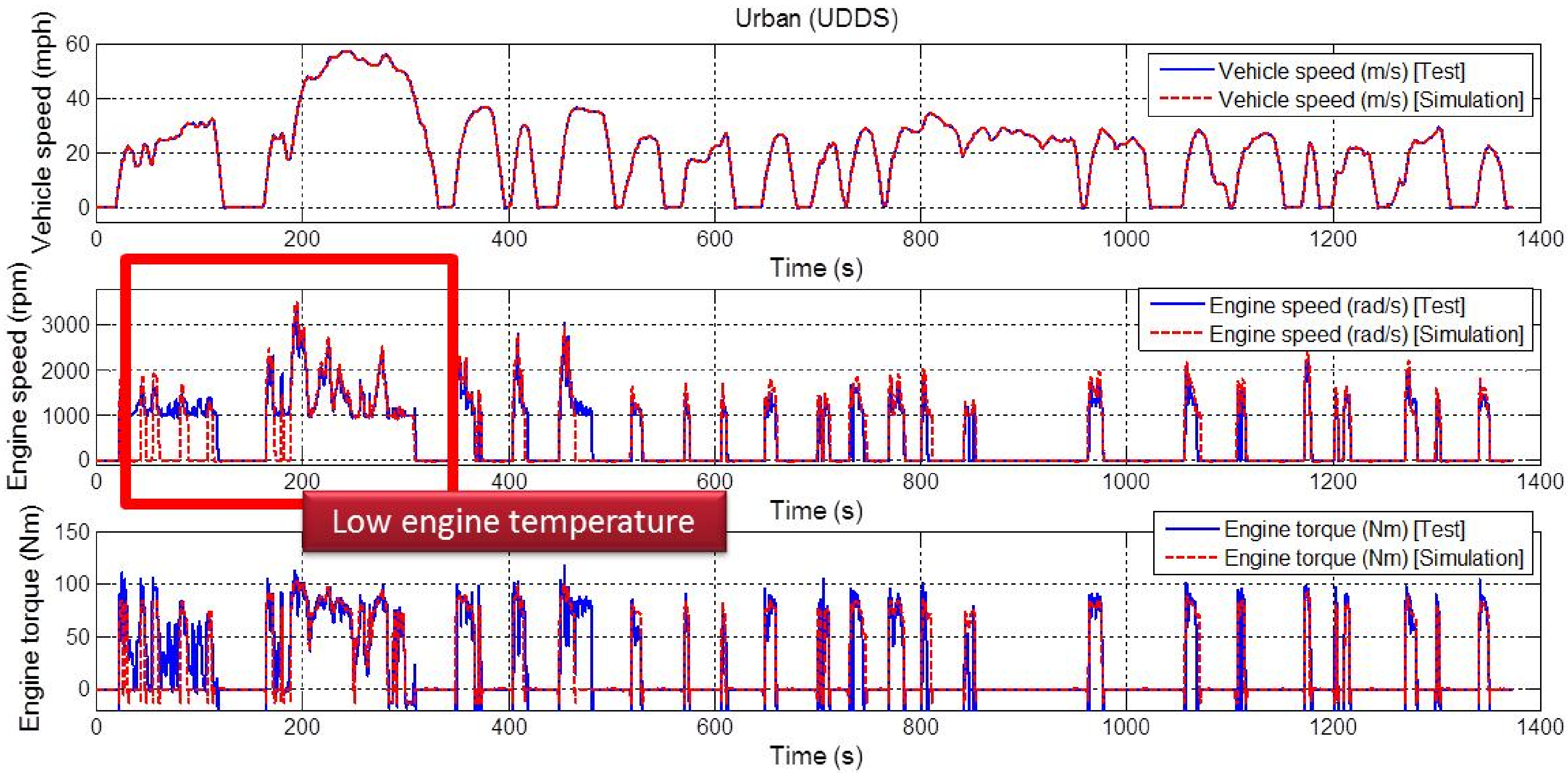
- The efficient accessory system, particularly the vehicle cooling system (VCS) and climate control system (CCS) is more important for high-efficiency vehicles because they have greater effect on the fuel economy.

Comparison of fuel economy impacts of auxiliary loads between a conventional vehicle and a high fuel economy vehicle (Earth Technologies Forum, NREL)



Relevance

Toyota Prius Validation under Ambient Temperature (FY11)



Toyota Prius model was validated under ambient temperature, but component operation differences remain due to thermal events, even at ambient conditions

Approach

OEM
- Automotive manufacturer
- Battery manufacturer

Compo. Model
- VCS
  - Engine, Transmission, Electric Machine
- CCS
  - Battery TMS, Cabin, Air conditioner, Heater

National Laboratory

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Compo. Validate
- Standalone validation

Vehicle Control
- Supervisory controller

Vehicle Validate
- Under Ambient Temperature

APRF
- Advanced Power train Research Facility
- In-depth Vehicle Testing Work

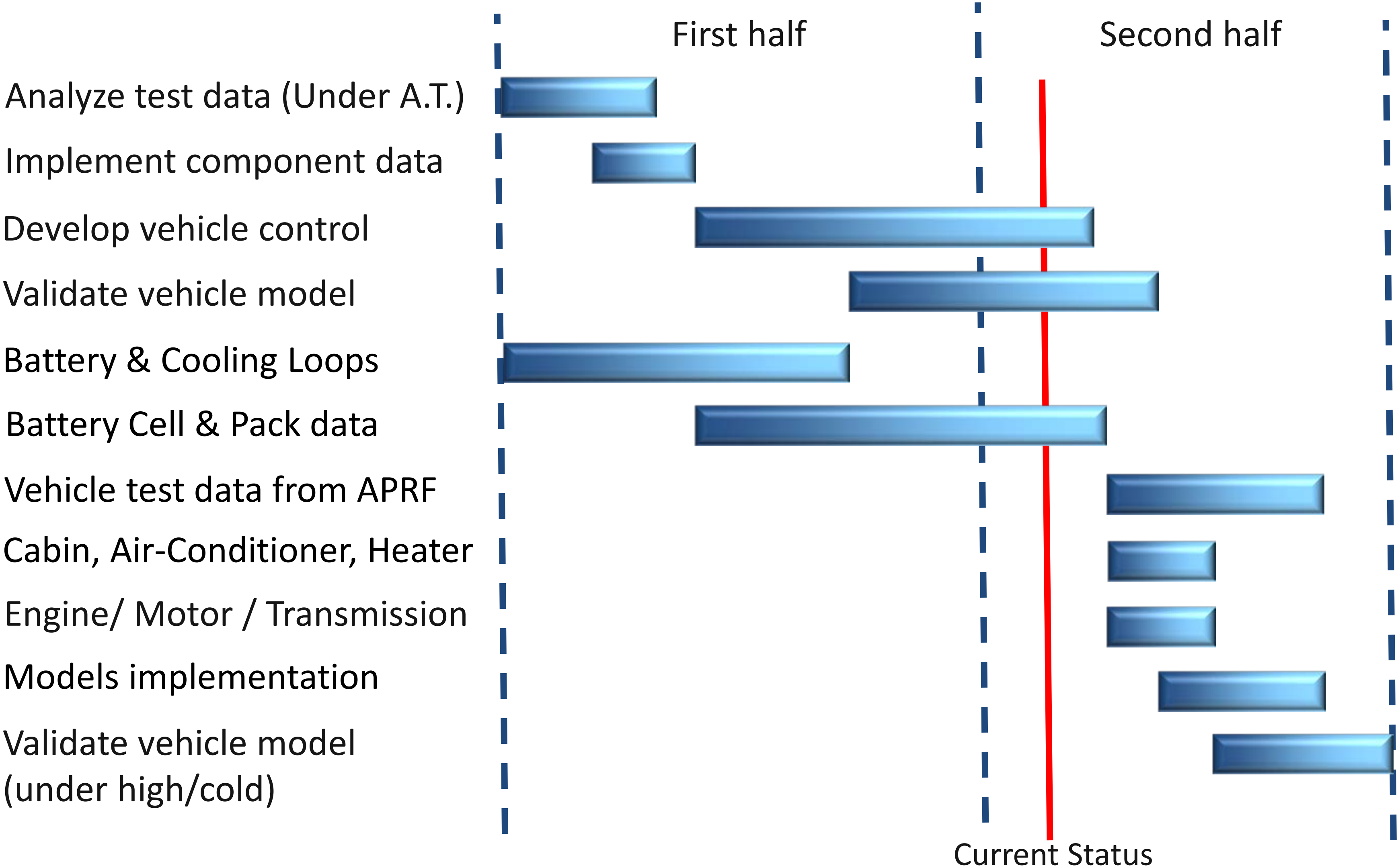
Compo. Validate
- Standalone validation
- Under different temperature conditions (hot/cold)

Vehicle Control
- Supervisory controller

Vehicle Validate
- Under different temperature conditions (hot/cold)

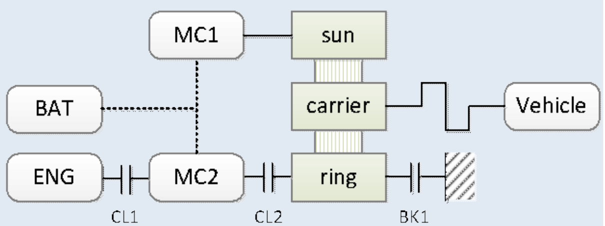
FY13
- Thermal model of advanced technology
- Operating strategy of thermal management system

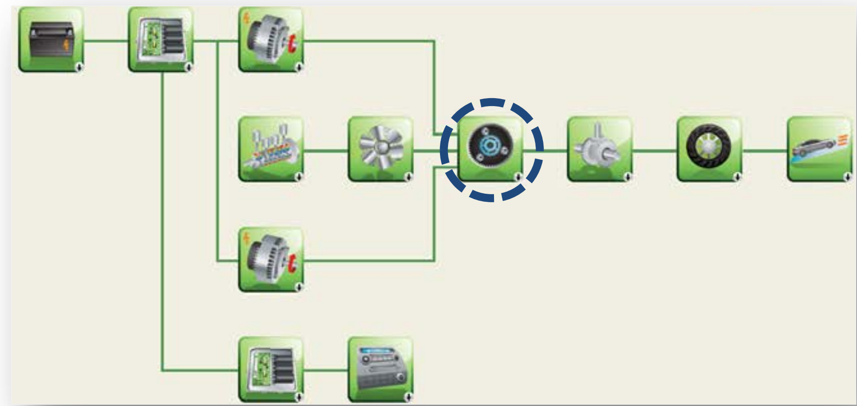
Milestones


First half
Second half
Analyze test data (Under A.T.)
Implement component data
Develop vehicle control
Validate vehicle model
Battery & Cooling Loops
Battery Cell & Pack data
Vehicle test data from APRF
Cabin, Air-Conditioner, Heater
Engine/ Motor / Transmission
Models implementation
Validate vehicle model
(under high/cold)
Current Status

Technical Accomplishment
GM Volt Vehicle Validation under Ambient Temperature

- Control model in Autonomie® - vehicle configuration

	GM Volt
Conf.	
Test mass	1814 kg
Engine	1.4L, 62kW
Battery	288 cells, 16kWh
Motor	111kW / 55kW
Final drive	2.161



The control model is deployed and validated in Autonomie®.

Our approach is to load necessary components and build Volt and apply the developed control model in the vehicle

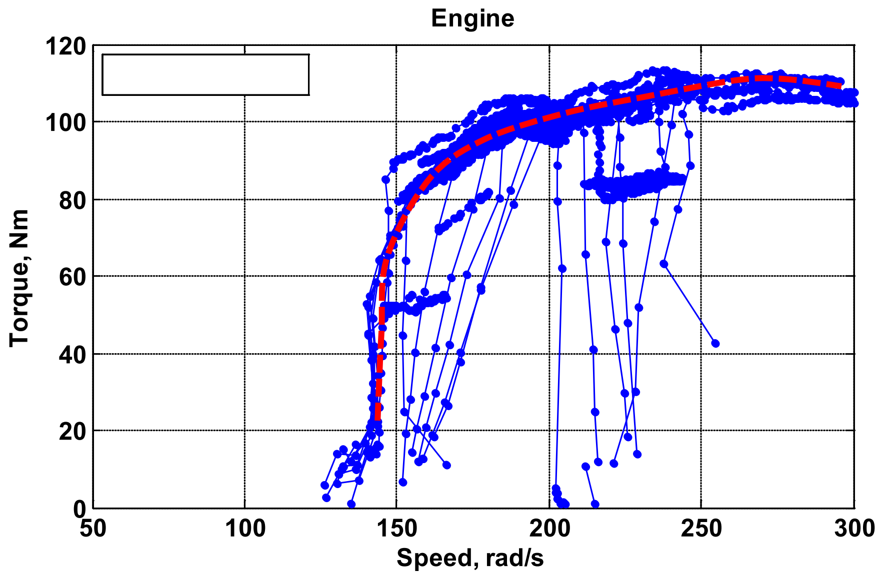
Transmission model is developed in SimDriveline to allow for modeling of detailed losses

Technical Accomplishment

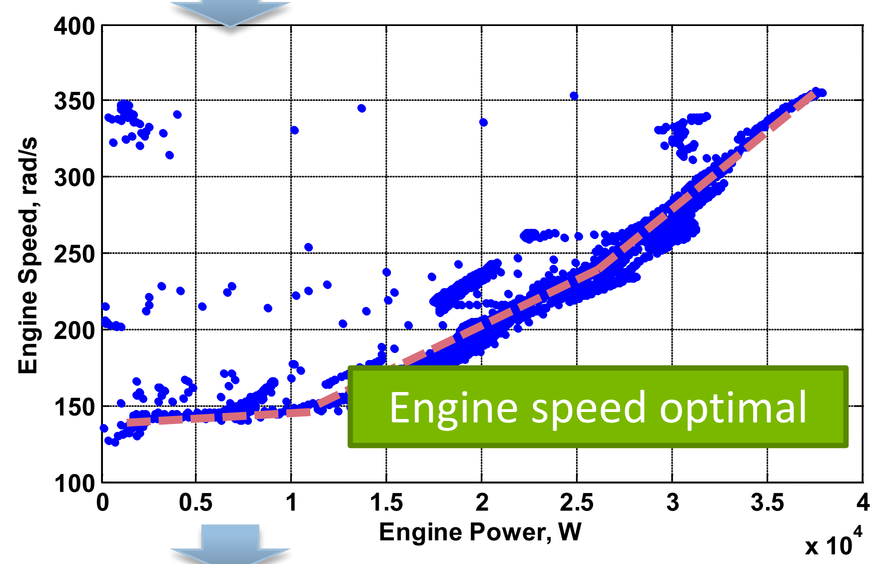
GM Volt Vehicle Validation under Ambient Temperature

- Test data analysis for control model - Engine operating target from all tests

From UDDS CS-driving, 5 Steady-Speed driving test



Engine power demand



Engine torque desired

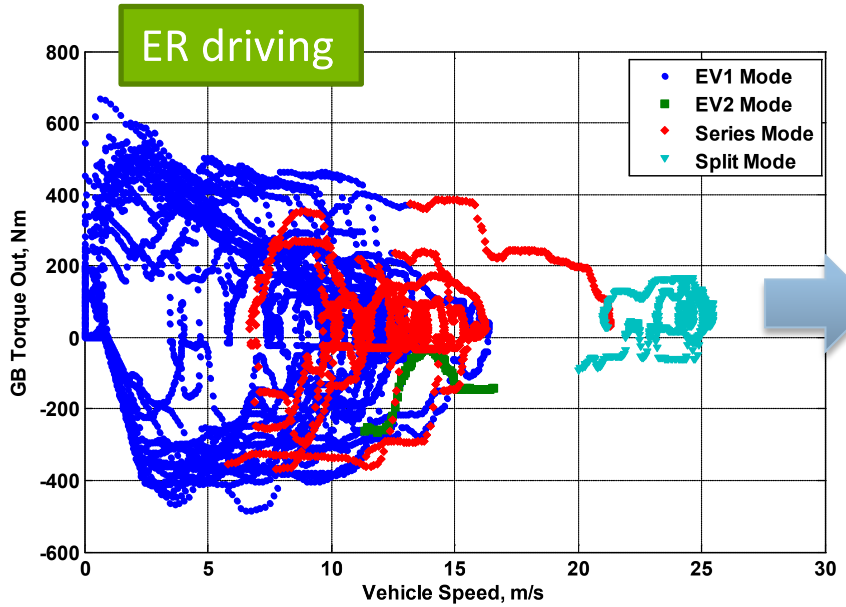
The engine torque signal comes from CAN signal bus.

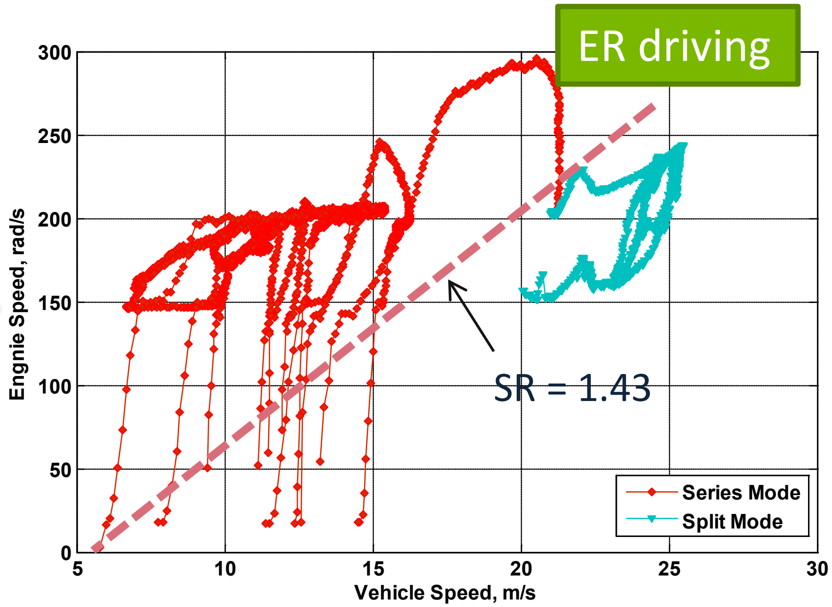
Engine speed operating points are obtained according to the engine power.

Technical Accomplishment

GM Volt Vehicle Validation under Ambient Temperature

- Test data analysis for control model - GB Mode on ER driving



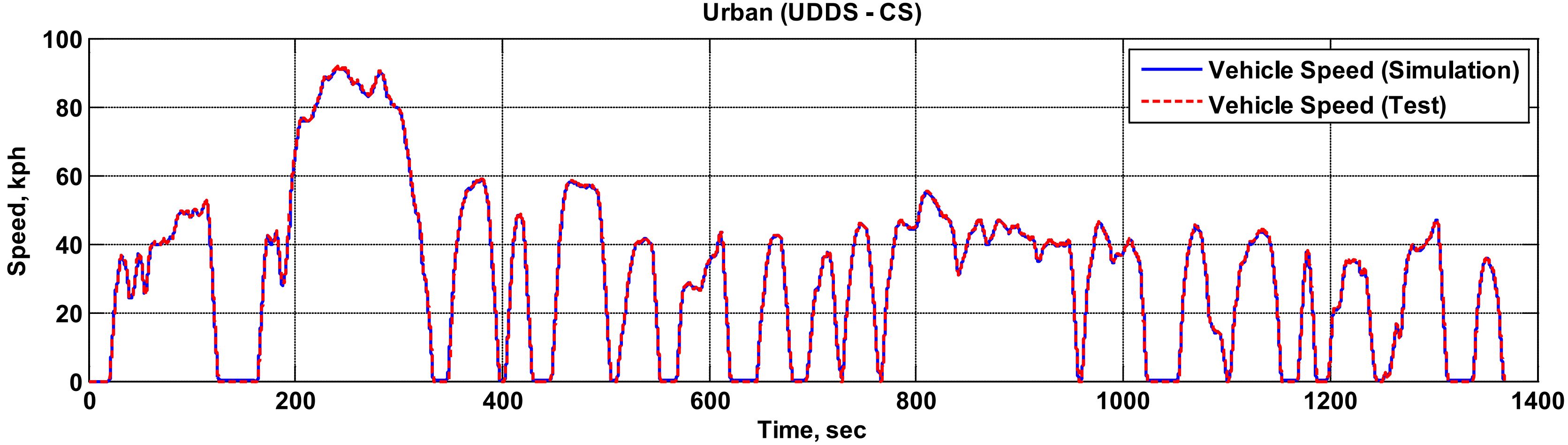


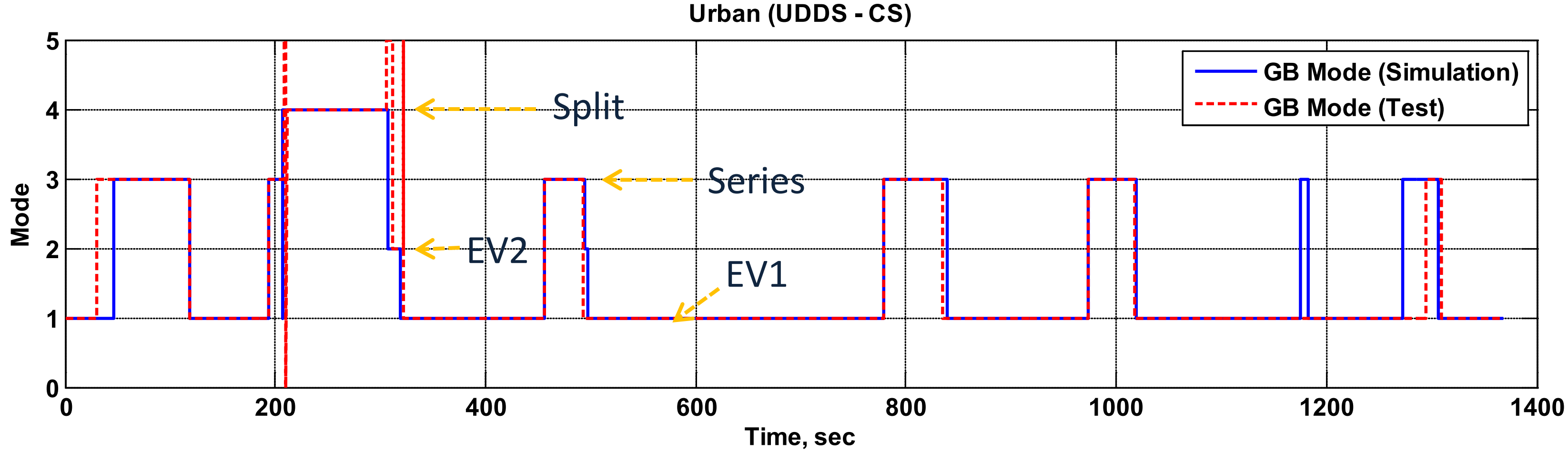
After we convert these results into new map by using vehicle speed and engine speed indexes, the mode selection rule can be defined based on the speed ratio

The logic was validated for multi-mode hybrid system by using vehicle test data.

Technical Accomplishment
GM Volt Vehicle Validation under Ambient Temperature

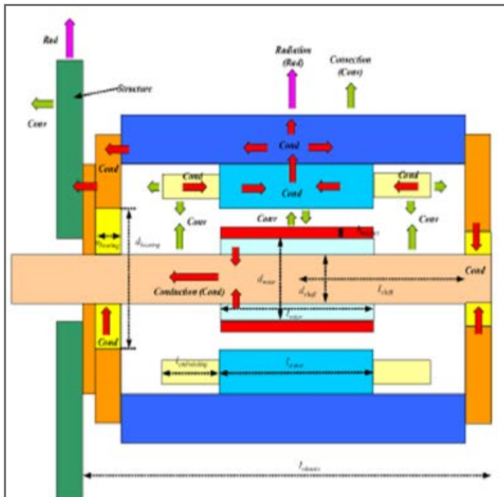
- Model Validation in Autonomie® - urban driving schedule (ER driving)



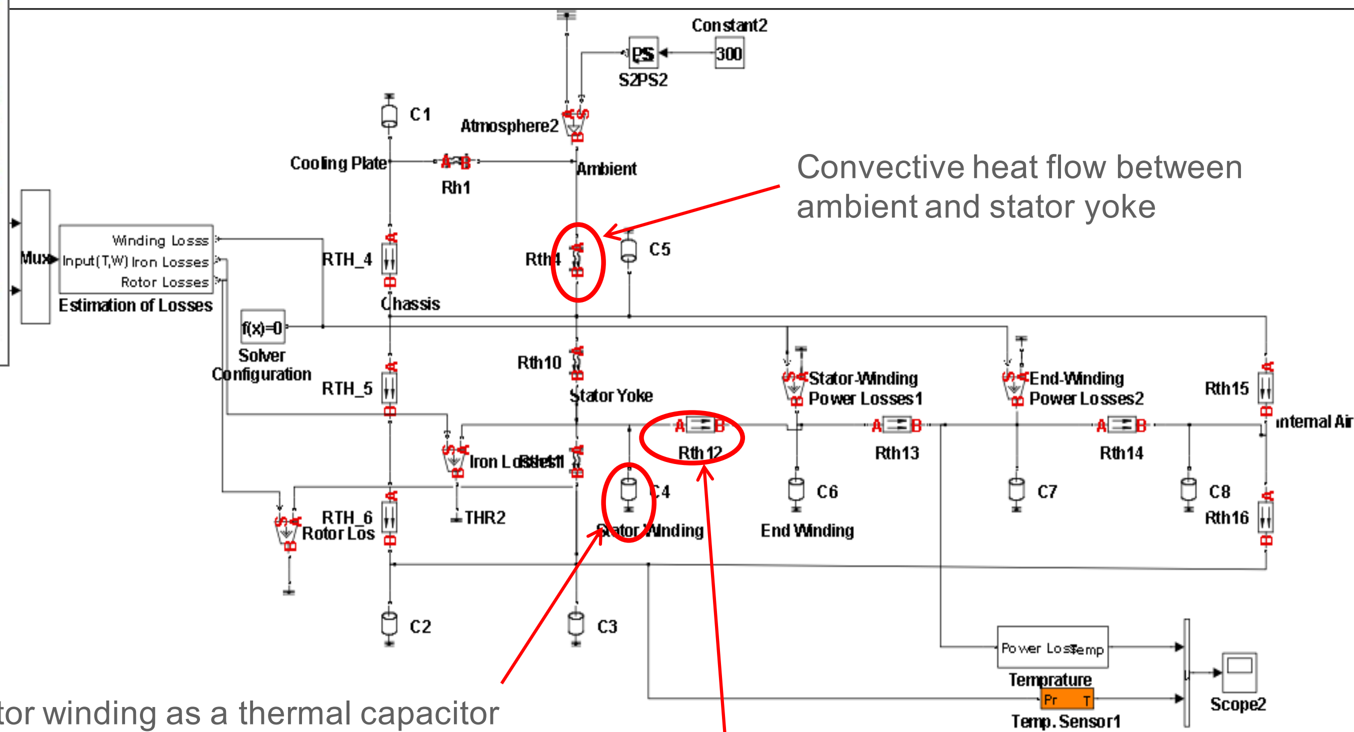


Technical Accomplishment

Electric Machine Thermal Model Developed



Thermal model represented as equivalent thermal circuit of the motor



Convective heat flow between ambient and stator yoke

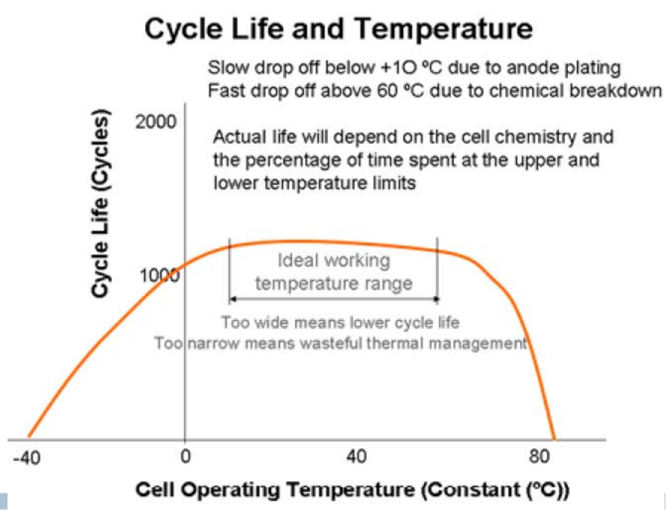
Thermal circuit can be constructed directly in Simulink using Simscape (Simulink toolbox)

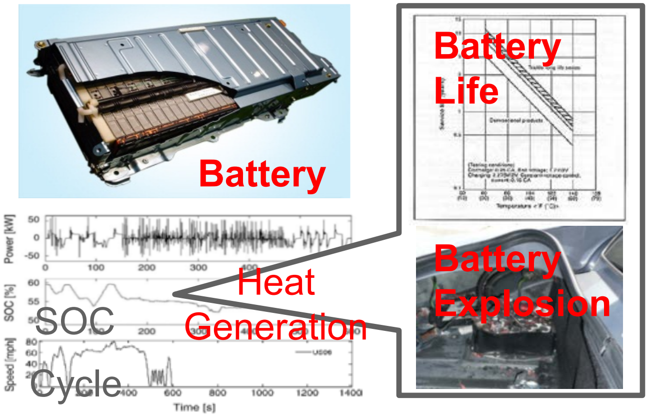
Stator winding as a thermal capacitor

Conductive heat flow between stator and end winding

Technical Accomplishment
Battery Thermal Model Implemented in Autonomie®

- **Battery Thermal Management System**
  - Lithium ion battery – Charging / Discharging during driving cycle
    - Heat generation due to electrochemical reaction & electrical resistance
    - Increase battery temperature → to prevent thermal runaway
  - Manage the temperature of battery pack
    - Maintain even temperature distribution
    - Keep the temperature in optimum temperature

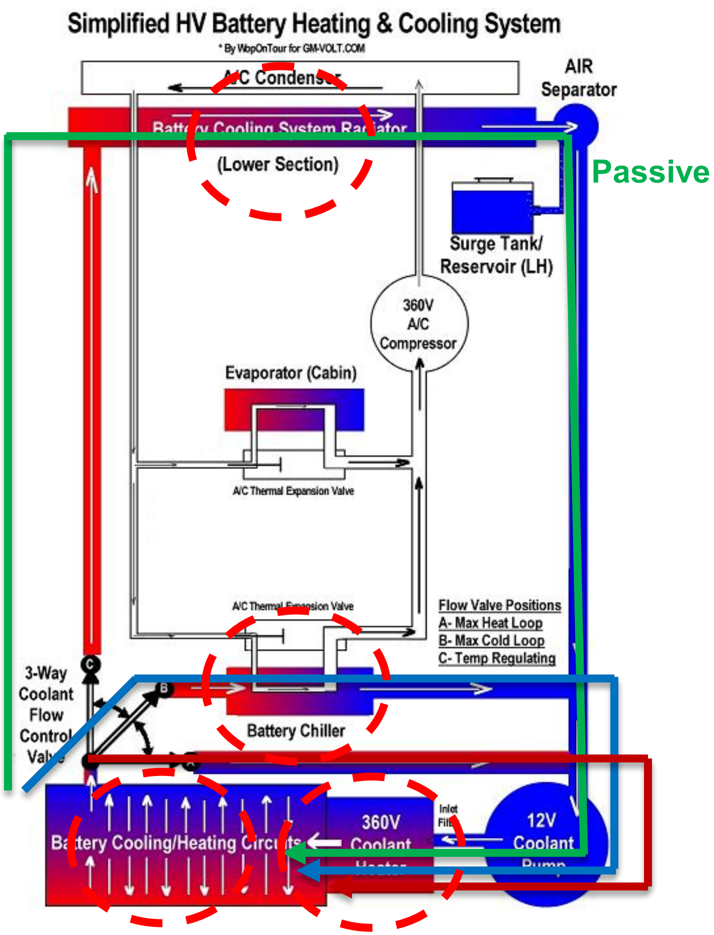




Technical Accomplishment

Battery Thermal Model Implemented in Autonomie®

- GM Volt TMS

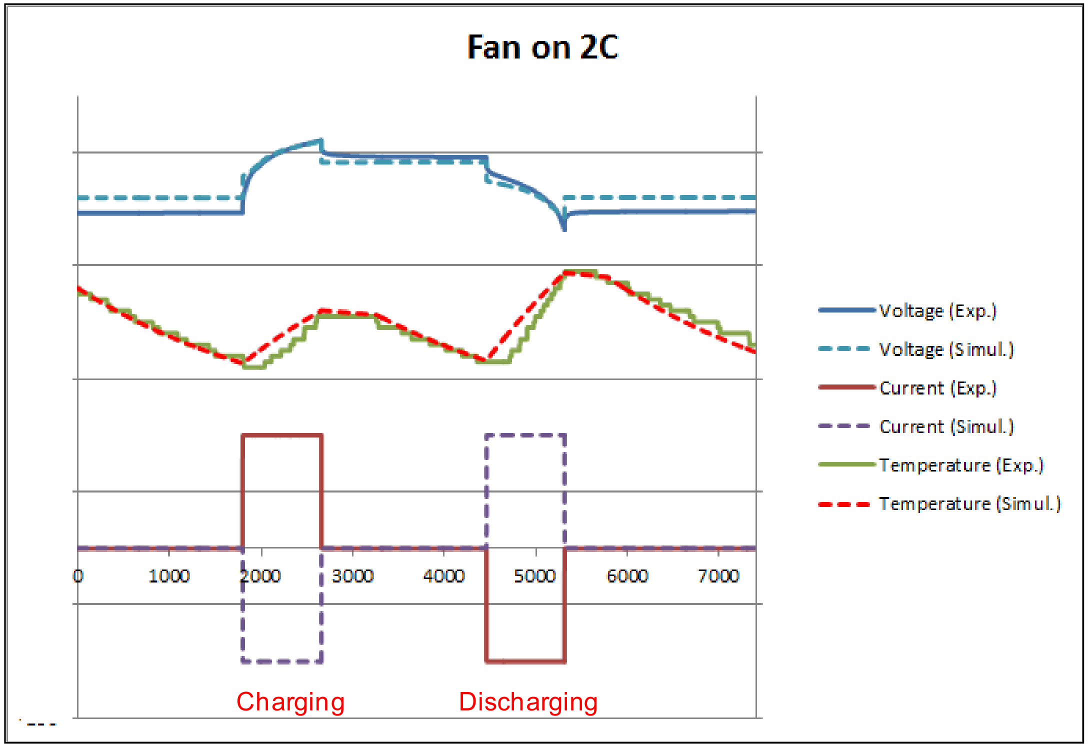


- Components
  - Pump
  - Chiller
  - Heater
  - Radiator – fan
  - Control valve – control signal
- Cooling mode
  - Active cooling : pump, chiller
  - Passive cooling : pump, radiator, radiator fan
  - Bypass : pump
  - Heating : pump, heater
- Heat exchange
  - Battery : battery coolant – battery
  - Radiator : battery coolant – ambient air
  - Chiller : battery coolant – chiller coolant
  - Heater : battery coolant – heater

Technical Accomplishment
Battery Thermal Model Validation

- Air cooling validation
  - Use OEM air cooling experimental data – pulse charging / discharging
    - Validation at battery pack level

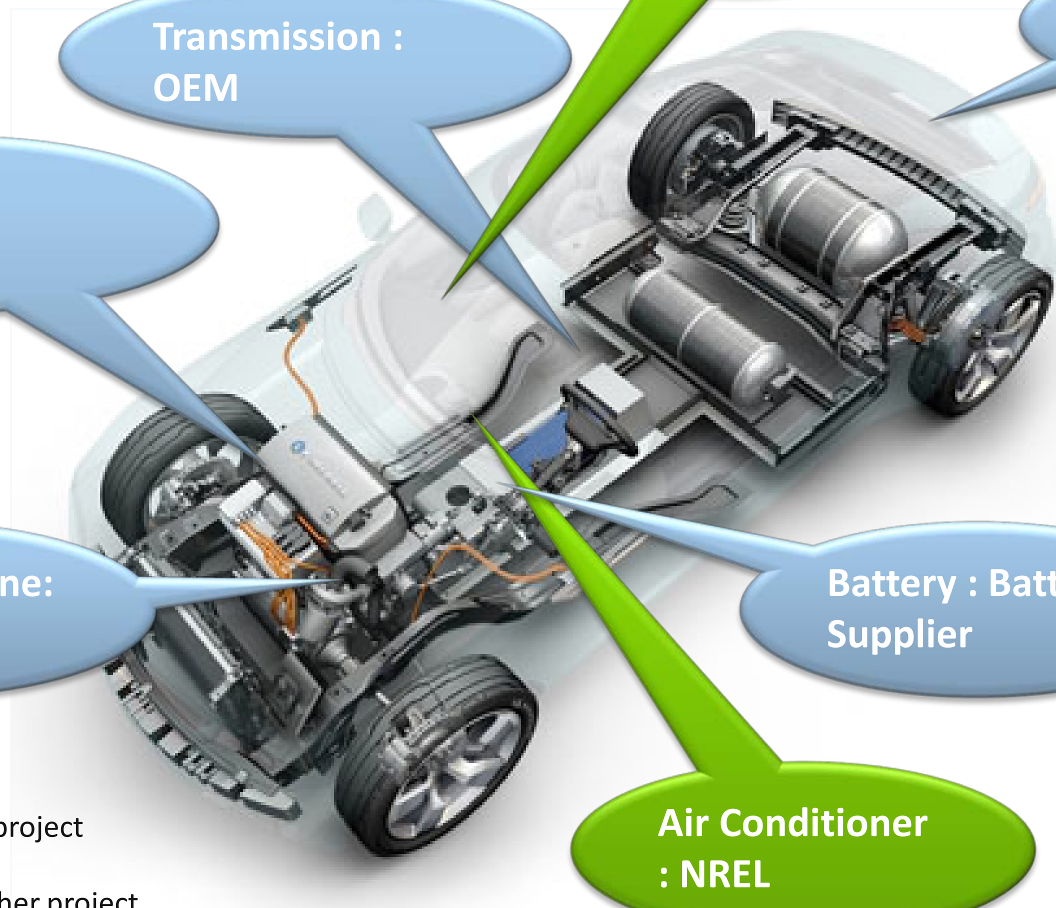
- Validation results



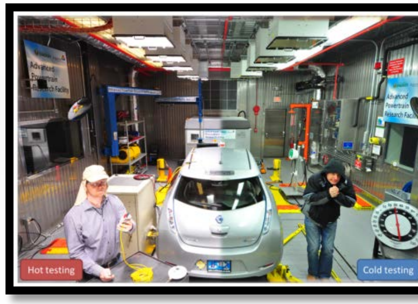
→ Steps

- Forced convection
- Pulse charging
- Natural convection
- Forced convection
- Pulse discharging
- Natural convection
- Forced convection

Collaboration and Coordination with Other Institutions



APRF



Funded under this project

Funded under another project

Proposed Future Activities

- **On going work for FY12**
  - Validate with liquid coolant experimental data at vehicle level
  - Engine thermal model (partnership with MathWorks)
  - Integrated model of engine, cabin, electric machine and transmission in Autonomie®
  - Validate thermal the behavior of each thermal system of component and fuel economy of the vehicle under various vehicle driving conditions

- **Proposed Future Work**
  - Complete the vehicle thermal validation of both the Toyota Prius and the GM Volt
  - Develop vehicle thermal models for other powertrain configurations (i.e., conventional, battery electric vehicle…)
  - Develop a vehicle level thermal management control strategies to optimize the energy efficiency of the system with the goal of minimizing fuel and electrical consumptions.

Summary

- Developed GM Volt battery thermal management system (TMS) for liquid cooling
  - Components pump, chiller, radiator, radiator fan, heater
  - Active cooling, Passive cooling, bypass, heating
- Validated the TMS with OEM experimental data
  - Change properties of liquid coolant → use air properties
  - Add activation loss
  - Passive cooling, Natural convection
- The test data was analyzed to define the component models.
  - The transmission model was developed based on the original schematic of the system
- A control strategy for both vehicles including temperature will be generated based on testing results.