Vehicle Design and Evaluation —— Modeling, Simulation, and Analysis of Hybrid-Electric Powertrains and Vehicles

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Project Description

This project is intended to provide the powertrain and vehicle modeling and simulation tools needed to evaluate emerging driveline technologies and alternate fuel options expected to be utilized by the auto industry for passenger cars, SUVs, and light trucks as they proceed to meet the new fuel economy standards and the availability of alternative fuels such as ethanol. Various hybrid driveline configurations such as the GM, Chrysler, BMW dual mode and the GM Volt series will be modeled and compared with the more standard parallel and Prius planetary arrangements in terms of system efficiency and cost and vehicle fuel consumption. Special attention will be given to new engines such as clean diesel, direct injection gasoline, and homogeneous combustion (HCCI). All the models will be validated using published fuel consumption and greenhouse gas emission data from the US EPA and European sources.

Project Objectives

- ❑ Development of brake specific fuel consumption maps as a function of RPM and torque for advanced engines and fuels.
- ❑ Development of a model for a continuously variable transmission that includes torque transfer losses and electric operation of actuator drives.
- ❑ Modeling of various single-shaft hybrid driveline configurations
- ❑ Modeling of various planetary hybrid driveline configurations
- ❑ Optimization of the control strategy for the various hybrid driveline configurations
- ❑ Modeling of various emerging lithium-ion battery technologies
- ❑ Modeling of various ultracapacitor technologies and optimization of control strategies
- ❑ Computer simulations of hybrid vehicles using the various models developed and analysis of the results

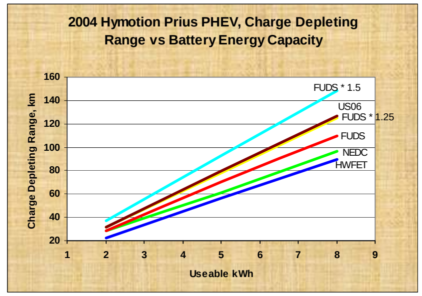
Project Milestones

- ❑ A model was developed for the gasoline engine in the 2006 hybrid Honda Civic that includes the effects of cylinder deactivation, variable valve timing, and reduced friction when the engine is not being fueled. The model was prepared based on SAE papers presented by Honda.
- ❑ A model was developed for a continuously variable transmission based on test data taken at UC Davis in MS theses with Prof. Frank and electric operation of the actuators in the CVT.
- ❑ Modeling of the Prius planetary and Civic single-shaft hybrid drivelines for HEVs and PHEVs using lithium-ion batteries was completed and validated using published EPA fuel economy test data.
- ❑ Computer simulations of PHEVs of different designs on various driving cycles were performed and analyzed.
- ❑ Paper presented at EET-2008, Geneva, Switzerland, entitled "**Plug-in Hybrid-Electric Vehicle Powertrain Design and Control Strategy Options and Simulation Results usng Lithium Batteries** "

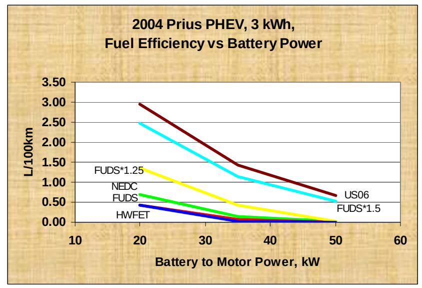
Collaboration Goals and Interests

It is our intention to collaborate with other threads inside STEPS as well as with groups and laboratories outside of UC Davis. It is important that vehicle inputs used in the other threads reflect realistic expectations for improvements in vehicle characteristics and cost reductions in future years and how the characteristics/costs of the various vehicle technology/fuel combinations are likely to change relative to one another. The vehicle design and evaluation tools will be formulated to facilitate these cross-thread comparisons. Collaborations have been started with Argonne National Lab and the Idaho National Lab to obtain test data needed to model the components in the drivelines and to validate the simulation results for the hybrids, especially the PHEVs.

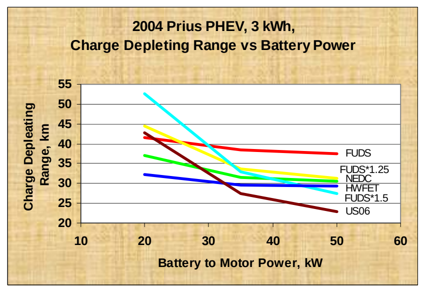
Selected Results



The balance between battery size and charge depleting range is critical for plug-in hybrids. Extended electric operation means reduced fuel consumption and GHG emissions but batteries are expensive and must not be prohibitively so for plug-ins to be popular. This figure shows the relationship of the useable battery capacity to the charge depleting range for a plug-in Prius. The relationship is essentially linear as additional lithium batteries do not add enough weight to affect the energy use. Battery costs can be estimated from their capacity. Several drive cycles are simulated to allow better insight into real world performance. The FUDS*1.5 drive cycle is most representative of actual driving conditions. The longest charge depleting ranges are for the FUDS*1.5 because the batteries are underpowered for a significant amount of the drive cycle requiring power from the combustion engine instead.

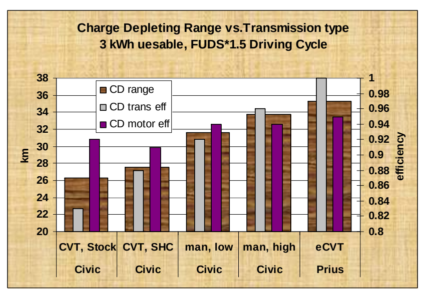


The power available from the batteries to the electric motor determines the extent to which a plug-in hybrid can function as an all electric vehicle in the charge depleting mode. This graph shows the relationship of fuel mileage to available battery power to the traction motor for the charge depleting mode under various drive cycles. More available battery power allows the vehicle to operate more like an electric vehicle, reducing the engine power required and improving the fuel mileage. At 35 kW the vehicle is able to operate essentially as all electric for the slower drive cycles. For the faster drive cycles, FUDS*1.5 and US06, not even a 50 kW battery allows for truly all electric operation.



Battery power also affects the charge depleting range. The more power available to the electric motor the more it will operate in the all electric mode and the charge depleting range will consequently be shorter. The charge depleting range for the faster driving cycles are most affected by the change in battery power, decreasing by half for an increase from 20 kW to 50 kW.

The battery power and capacity as well as motor size for plug-in hybrids needs to consider the extent and range of the desired all electric operation.



Various hybrid architectures are available to be used in future Plug-in configurations. However, not all are equally suited for all electric operation in the charge depleting mode. The figure to the left shows the effects of transmission type and efficiency on charge depleting range for parallel plug-in hybrid configurations. The CVT is effective for improving charge sustaining fuel mileage because it allows the engine to operate more efficiently but its poor mechanical efficiency adversely affects the all electric operation. Mechanical transmissions with less energy loss allow for improved all electric range over the CVT. In the Prius the traction motor is connected directly to the drive shaft further improving the charge depleting range over the parallel hybrid with manual transmission. Plug-in hybrids should be designed with special attention to the efficiency of the all electric operation.

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