Finding Ultimate Limits of Performance for Hybrid Electric Vehicles

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Hybrid electric vehicles are seen as a solution to improving fuel economy and reducing pollution emissions from automobiles. By recovering kinetic energy during braking and optimization the engine operation to reduce fuel consumption and emissions, a hybrid vehicle can outperform a traditional vehicle. In designing a hybrid vehicle, the task of finding optimal component sizes and an appropriate control strategy is key to achieving maximum fuel economy.

In this paper we introduce the application of convex optimization to hybrid vehicle optimization. This technique allows analysis of the propulsion system's capabilities independent of any specific control law. To illustrate this, we pose the problem of finding optimal engine operation in a pure series hybrid vehicle over fixed drive cycle subject to a number of practical constraints including:

- nonlinear fuel/power maps
- min and max battery charge
- battery efficiency
- nonlinear vehicle dynamics and losses
- drive train efficiency
- engine slew rate limits

We formulate the problem of optimizing fuel efficiency as a nonlinear convex optimization problem. This convex problem is then accurately approximated as a large linear program. As a result, we compute the globally minimum fuel consumption over the given drive cycle. This optimal solution is the lower limit of fuel consumption that any control law can achieve for the given vehicle and drive cycle. In fact, this result provides a means to evaluate a realizable control law's performance.

We carry out a practical example using a spark ignition engine with lead-acid (PbA) batteries. We close by discussing a number of extensions that can be done to improve the accuracy and versatility of the methods. Among these extensions are improvements tin accuracy, optimization of emissions and extensions to other hybrid vehicle architectures.