Emission-aware energy management of hybrid vehicles

1 Background

In hybrid vehicles a combustion engine is complemented with an electric generator, an electrical machine, and a battery. An after-treatment system is used to reduce exhaust emissions from the combustion engine. A key challenge from a controls perspective is to use these subsystems as efficiently as possible in the vehicle's various use-cases.

For electric hybrid vehicles, it is common to implement an energy management system that acts as a supervisory controller, which primarily determines how much and when power should be delivered from the electric machine and combustion engine. However, modern energy management systems largely neglect the dynamic effects of the combustion and after-treatment systems. This project aims to reduce current inefficiencies in overall vehicle behavior with respect to both emissions and fuel consumption.

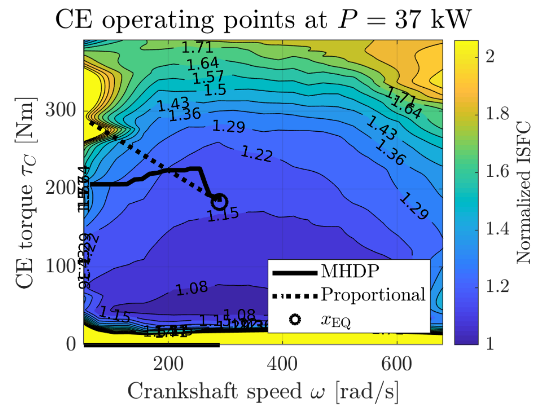

Figure 1: Representative combustion engine (CE) transient operating points for optimal (MHDP) and traditional (proportional) controllers, eventually reaching equilibrium point x_{EQ}.

2 Method

This project will focus on:

- Assessing the potential to create an energy management system that is aware of the (full) state of the combustion process and after-treatment system.
- Designing an energy management control architecture that can utilize state-information from the combustion system (including the after-treatment system) to enable near-optimal control of the relevant subsystems for a range of vehicle use cases.
- Demonstrating the benefit of the developed control structures by vehicle testing using the Chalmers hybrid test rig for a limited set of drive scenarios.

These goals will be achieved through work in two distinct fields: we require new systems control methods and tools to solve the stated problems, and experimental studies to evaluate the performance of the proposed controller.

3 Results

To date, most of the work in this project has focused on developing and experimentally validating two extensions to methods of solving optimal control problems to fill a knowledge gap, ultimately allowing us to solve the relevant control theory problems in this project.

The first method, named *multi-pass iterative dynamic programming* allows for very quickly calculating a best-case control reference for the after-treatment aware control problem, which we can then compare with practically realizable controllers as well as today's controllers.

The second method, named *multi-pass iterative dynamic programming* (MHDP), allows for computing the solution to a constant set-point non-linear optimal control problem. By "constant set-point control", we mean the task of controlling a dynamic system's state such that it remains constant for a long time. Crucially, MHDP is constructed in such a way that the result of slow off-line computations allows for the practical realization of a fast on-line optimal controller, typically requiring on the order of 5-10 KiB of nonvolatile memory, a few bytes of RAM, and 10 — 100 CPU instructions per real-time control call; requirements easily satisfied by almost all existing embedded systems.

4 Conclusions and outlook

The use of an optimal controller, e.g. as generated by MHDP, allows for more efficient control of relevant automotive subsystems. An example is shown in Figure 1, where we fuel-optimally control a combustion engine to reach a given operating point. As the controller is optimal even during the transient a more efficient path to the equilibrium operating point can be chosen.

In the future, we plan to apply the developed methods in the context of after-treatment control. In particular, we will consider cases where the goal is to minimize fuel consumption, including during transient operation, while generating a given average level of emissions.