Dynamic Programming Algorithms for Optimal Control Problems in Hybrid Electric Vehicles

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This thesis deals with the development of computer algorithms and their software implementation for the design of optimal *energy management strategies* (EMSs) for *hybrid electric vehicles* (HEVs) in an offline environment.

Currently, optimal control techniques for EMS design are unable to handle complex simulation models because they are computationally over demanding. This limits the ability of automotive manufacturers and researchers to explore the complexity of hybrid electric powertrains in the design phase and therefore to fully exploit their benefits. The underlying goal of this work is to overcome these shortcomings by developing offline optimal control methods suitable for higher-fidelity models. This goal is pursued in two research branches, corresponding to the two parts that compose this thesis.

The first part is centered around the well-established technique of dynamic programming. First, an open-source MATLAB toolbox for dynamic programming is developed. The toolbox includes state-of-the-art methods to overcome the potential numerical issues of the technique which typically arise in practical implementations. Then, we shift our focus from algorithmic aspects to modeling aspects to investigate the interaction between powertrain modeling choices and the algorithm. We conduct a systematic analysis and define ad/hoc evaluation criteria. We then develop a case study and we perform extensive numerical experiments to support our analysis and we conclude with a set of recommendations that can be drawn from the evidence. Both of these contributions constitute an improvement to the existing practice of optimal EMS design with dynamic programming.

The second part is centered around a less known but promising technique called differential dynamic programming, with the prospect of overcoming the curse of dimensionality while keeping the benefit of guaranteed optimality. The relevant literature is reviewed to lay out the theoretical foundations of the algorithm. The theory is then used to develop a software implementation making use of modern computational techniques and tools to enable the technique's application to a real-life engineering problem, which constitutes another major contribution of this thesis. Finally, a EMS design ap-

plication for a series hybrid powertrain is presented using the software, in order to test its robustness and computational capabilities. The results show great promise towards the ambitious goal of developing a broad-purpose offline EMS design tool capable of handling high-fidelity simulation models.