Optimal Computer-aided Engineering of Propulsion and Brake Systems for Electrified and Automated Road Vehicles

Doctoral Dissertation
Doctoral Program in Mechanical Engineering (33th Cycle)

Optimal Computer-aided Engineering of Propulsion and Brake Systems for Electrified and Automated Road Vehicles

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Summary

Electrification of powertrains and automatization of vehicle operation represent two of the deep transformations currently being undertaken by the automotive industry. Innovative computer-aided engineering (CAE) tools need therefore advance to face these profound and partially unresolved, yet stimulating, challenges. This doctoral thesis aims at developing vehicle-level optimization-based CAE methodologies that might contribute to develop propulsion and brake systems of the next generation electrified and automated road vehicles.

An energy management strategy for electrified powertrains that enables the rapid prediction of the ideal fuel economy capability of hybrid electric vehicles (HEVs) while guaranteeing smooth drivability and ease of adaptation to various HEV powertrain architectures is developed first in this thesis under the name of slope-weighted energy-based rapid control analysis (SERCA).

The upgrade of optimal off-line HEV energy management finds then discussion by integrating the prediction of the high-voltage battery lifetime through the implementation of a suitable battery ageing model. A dedicated experimental campaign allows validating and calibrating the retained numerical ageing model while assessing the impact of the implemented battery sensitive HEV energy management on battery lifetime.

A CAE methodology is consequently proposed for sizing electrified road vehicle powertrains at an overall car maker vehicle fleet level by considering different evaluation criteria involving retail price, compliance with current and future regulatory CO_2 emission requirements, drivability, high-voltage battery lifetime and real-world operative costs as example. The case study performed on a group of different vehicle models embedding the same electrified powertrain being controlled by the SERCA algorithm previously introduced identifies a plug-in HEV as the most robust propulsion system architecture solution for the retained optimization targets and considering different 2030 oriented regulatory scenarios.

Enabling the automated development of the on-board HEV on-line control logic at an early electrified powertrain design phase finds then discussion by developing a machine learning based energy management strategy that can flexibly be adapted to different multimode power-split HEV powertrain architectures. Results suggest that the HEV design optimization procedure may produce different outcomes and demonstrate more effective when the evaluation of the on-line controlled operation is integrated.

The final part of this doctoral dissertation considers battery electric vehicles (BEVs). An optimal design framework for automated BEVs is first developed by identifying the pure electric powertrain sizing candidates exhibiting the best performance in driving conditions optimized off-line through a proposed dynamic programming based control approach, with focus on vehicle-to-vehicle (V2V) automated driving. Obtained results aim at quantifying the amount of energy savings and the passenger comfort improvement for V2V automated driving depending on the considered mission and BEV powertrain design. Moreover, remarkable changes in the ranking of optimal BEV design solutions are observed based on the specific percentage of the vehicle lifetime travelled as automated following car in the off-line optimized V2V scenario.

Finally, an optimization-based CAE methodology for hydraulic brake systems of BEVs is proposed that might allow achieving diversified sizing targets such as downsizing the overall brake system thanks to the regenerative torque contribution and enhancing the energy recovery capability of the BEV powertrain while complying with brake system safety standard requirements. A case study suggests the effectiveness and the flexibility of the developed CAE methodology in promptly identifying and assessing sub-optimal design alternatives for both front-wheel drive (FWD) and rear-wheel drive (RWD) BEV powertrain arrangements. Furthermore, compared with the RWD option, the FWD powertrain layout appears considerably favorable for a BEV in terms of electrical energy recovering capability during braking.

A suite of practical and flexible CAE tools finds detailed illustration in this way to enable the development of energy-efficient and user-oriented next generation electrified and automated road vehicles.