Multi-objective Optimisation of a Hybrid Electric Vehicle: Drive Train and Driving Strategy

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Abstract. The design of a Hybrid Electric Vehicle (HEV) system is an energy management strategy problem between two sources of power. Traditionally, the drive train has been designed first, and then a driving strategy chosen and sometimes optimised. This paper considers the simultaneous optimisation of both drive train and driving strategy variables of the HEV system through use of a multi-objective evolutionary optimiser. The drive train is well understood. However, the optimal driving strategy to determine efficient and opportune use of each prime mover is subject to the driving cycle (the type of dynamic environment, e.g. urban, highway), and has been shown to depend on the correct selection of the drive train parameters (gear ratios) as well as driving strategy heuristic parameters. In this paper, it is proposed that the overall optimal design problem has to consider multiple objectives, such as fuel consumption, reduction in electrical energy stored, and the 'driveability' of the vehicle. Numerical results shows improvement when considering multiple objectives and simultaneous optimisation of both drive train and driving strategy.

1 Introduction

A current environmental issue is the reduction of the total energy consumption of a passenger car. Despite their higher manufacturing cost, HEVs have been shown to be an effective way to substantially reduce fuel consumption [1]. Combining an electric motor and internal combustion engine to propel a vehicle results in an energy management problem. The fundamental issue of seeking for an effective and optimal strategy to split the power between thermal and electrical paths is addressed in this paper.

Guzzella and Sciarretta [2] have classified the optimisation of a HEV system in three layers, as follows: 1) Structural optimisation, where the objective is to find the best possible structure (arrangement of power train and prime movers);

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2) Parametric optimisation, where the objective is to find the best possible parameters for a fixed power train structure; and 3) Control system optimisation, where the objective is to find the best possible supervisory control algorithm and best parameters thereof. Guzzella and Sciarretta identify that these stages are not independent. However, due to the limitations of conventional optimisation techniques (nonlinear programming, dynamic programming) they have yet to be considered simultaneously. In this paper, the parametric optimisation, via an Evolutionary Algorithm (EA), for a fixed power train structure and for a supervisory control algorithm is simultaneously considered.

This problem could be seen as an optimisation problem in Dynamic Environments (DEs). Using Branke's criteria [3], it clearly has the characteristics of a DE: the change in optimum value (optimal distribution of the power between the thermal and electrical paths depends on time and energy usage of the vehicle), frequency of the change and severity of the change depend on the driving cycle. There is some degree of predictability of change: there are three main types of driving cycle. In the United States, the Urban Dynamometer Driving Schedule (UDDS – also known as the US federal test procedure, FTP-72) represents a city driving cycle. The federal highway driving cycle (FUDS) represents extra-urban and high speed driving, and in Europe the urban motor vehicle expert group (MVEG-95) represents a combined cycle. These driving cycles are standard profiles of speed and serve as test cycles for performance comparison among different vehicles on the same basis.

It has been discussed in [3] that the solution of an optimisation problem in a DE, solved via an EA, doesn't need to cope with the dynamics (the optimum doesn't change over time) if a controller strategy is involved, and then the problem becomes static for the optimiser. Thus, the success of the design relies on the effective selection and parameter optimisation of the driving strategy. Guzzella and Sciarretta [2] have classified the driving controller strategies as follows: 1) Heuristic control strategies where rules are set up to meet torque demand and vehicle speed [4,5,6]; 2) Optimal control strategies where minimisation of the fuel energy use over the entire cycle is sought subject to a constraint over the final state of charge (SOC) of the battery. This strategy needs detailed knowledge of the future driving condition, so its use is impractical. However, it serves as a basis of comparison for evaluating the quality of other control strategies [7,8,9]; and 3) Suboptimal control strategies or real-time control strategies consider that some *a priori* knowledge of future driving conditions is available during the actual operation and that the self-sustainability of the electrical path has to be guaranteed. The idea then is to perform online optimisation to find the optimal distribution of power. This strategy assumes that some instantaneous state variables are available to evaluate a cost function, which is in terms of the fuel consumption and the SOC variation [9,10].

In Sect. 2, the HEV model used for the optimal transmission design and optimal tuning of the driving control strategy is described. This is a sketched outline of the model used, and the interested reader is referred to [6].