Fuzzy Rule-Based Energy Management Strategy for a Parallel Mild-Hybrid Electric Bus

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I. Introduction

Fossil fuels are an unsustainable resource that have been identified as the leading cause of climate change. In 2016, the Transport sector became the largest contributing sector towards greenhouse gas (GHG) emissions in the UK for the first time [1]. The Transport sector is now responsible for over a quarter of the total UK GHG emissions. Alternative drivetrain architectures such as electric vehicles (EV) or hybrid electric vehicles (HEV) are capable of substantially less tank-to-wheel emissions than conventional vehicles. Increased uptake of these emerging technologies will become increasingly important as the UK strives to meet its future emissions targets.

As a HEV contains both mechanical and electrical drivetrain components, a supervisory powertrain control system (SPCS) is required to successfully coordinate the operation of every component. The fuel efficiency and emissions benefits of a HEV are largely determined by the performance of the energy management strategy (EMS) incorporated in the vehicle's SPCS. Determining the power split between the mechanical and electrical paths that minimises fuel consumption and emissions, whilst regulating the battery's state of charge and meeting vehicle performance targets, are often the main objectives of a parallel HEV EMS [2].

This paper aims to address the growing demand for novel EMSs specifically designed for hybrid electric buses (HEB). Due to the close collaboration with the industrial partner on this project, the objective of this study was to improve upon an existing EMS currently used on a production HEB developed by Wrightbus.

II. Methodology

To reduce the time and cost associated with physical testing, it has become common practice to use model-based design to develop control systems in a simulation environment. The vehicle model used in this study was developed using MATLAB/Simulink and first published by Stevens et al. [3]. The model can simulate the vehicle's performance when varying physical component parameters, as well as the logic within the EMS.

After thoroughly reviewing the existing literature, a fuzzy rule-based approach has been identified as a suitable solution for the energy management problem in a HEV. Fuzzy rule-based strategies are inherently robust to measurement noise, easily adaptable, can be tuned using offline optimisation, and can be implemented on the vehicle with a low computational burden [4]. A heuristically designed fuzzy logic controller (FLC) was developed to determine the motor torque request for the HEB during acceleration/cruise events. The inputs to the FLC are brake specific fuel consumption (BSFC) and state of charge (SOC). The FLC rule base is comprised of 30 simple if-then rules. The output of the controller is used to determine the motor torque request. The rules are defined so that when the BSFC is low, i.e. the engine is producing energy efficiently, the motor torque request will be low. This enables the EMS to reserve electrical energy when the engine is operating efficiently, and then deploy that energy when the engine would have otherwise operated in a region of low efficiency. Figure 1 illustrates how the motor torque request varies with BSFC and SOC.

The EMS present on the physical vehicle was simulated using Simulink and integrated with the vehicle model to establish a baseline for comparison [5]. The new fuzzy rule-based EMS was also integrated with the vehicle model, and both model variants were simulated using the Millbrook London Transport Bus (MLTB) drive cycle. All parameters within the vehicle model were identical for both simulations, and the only difference between both simulations was the logic used to determine the motor torque request.

III. Results and Discussion

As illustrated in Figure 2, the results from this test indicate a cumulative fuel consumption reduction of approx. 2.2% on the MTLB drive cycle when using the new strategy. As CO_2 is a by-product of hydrocarbon combustion, the results additionally indicate that the GHG emissions generated using the new strategy will also be reduced. Further research will incorporate the use of machine learning to determine the optimal FLC parameters that minimise the fuel consumption for any drive cycle analysed.

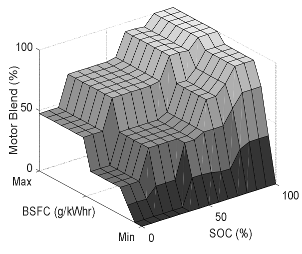

Figure 1. Output surface plot

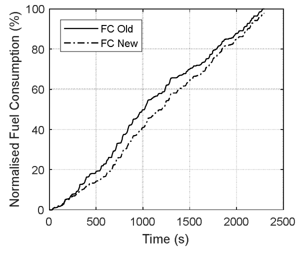

Figure 2. Fuel consumption comparison

IV. References

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