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A Study on Adaptive Power Split Strategy of HEV Using Nonlinear System Identification

Shiyu Zhao Ricardo UK, Ltd.

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Abstract

In this paper, an adaptive power split method is proposed and studied. A 48V mild hybrid vehicle model is used as an example to illustrate the adaptive power split method. First, the dynamic programming (DP) is used to find the global optimal fuel consumption and corresponding internal combustion engine (ICE) and electrical motor (EM) torque for the different random driving cycles, which are used to identify the power split model. After the optimal ICE and EM power split trajectories are obtained, the correlation between the output dataset of optimal power split for EM and the input dataset of the battery SoC, powertrain torque demand and engine speed are analysed. The regressors, which are terms of linear and nonlinear combinations of input and output parameters, are selected according to the correlation analysis. A nonlinear Auto Regressive eXogenous (ARX) model, which is structured by the selected regressors, is determined for the adaptive power split policy through the nonlinear system identification from the input and output dataset mentioned above. Finally, the obtained adaptive power split model is used for simulation in a different driving cycle. The fuel consumption of the adaptive power split method, rule-based strategy and dynamic programming (DP) strategy which is optimised against the certain driving cycle are compared. Although the adaptive power split is obtained based on the different vehicle driving cycle information, the fuel consumption of adaptive power split method is still slightly better than the rule-based strategy. The robustness and performance of the proposed method using nonlinear ARX model is proved in a certain degree.

Introduction

Apart from basic rule-based strategy [8], there are many advanced energy management strategies are implemented for hybrid vehicles. A typical one is the equivalent consumption minimization strategy (ECMS), which is to find the appropriate value of equivalence factor of electrical energy and fuel energy to obtain the optimal energy consumption. To achieve the best result of optimisation, the instantaneous minimization of equivalent energy on the Hamiltonian function shall satisfy the Pontryagin's minimum principle [5]. Such that ECMS can guarantee the optimal fuel consumption globally for a given driving cycle. But that global optimality is only possible with a given driving cycle that the vehicle speed, acceleration, deceleration, etc. are acknowledged in priori. In practice, such perfect equivalence factor is not robustness enough and may not be used for the real-world driving cycles. Alternatively, some research was carried out for the online adaptative ECMS which is applicable for the real-world driving cycles. The typical online adaptive ECMS is based on battery State-of-Charge (SoC) feedback, the equivalence factor is changed dynamically according to the SoC variation. When the SoC is high enough, the vehicle will use more electrical energy; when SoC is too low, the vehicle will use more fuel energy. The adaptive ECMS can maintain charge-sustainability, but obviously it only can provide a quasi-optimal or local optimal result.

In the implementation of ECMS, the instantaneous minimization problem on the Hamiltonian function can be interpreted as an equivalent power:

$$H = P_{Fuel} + \lambda P_{Batt} \tag{1}$$

Where P_{Fuel} is the fuel power, e.g. the ICE power using the chemical energy from fuel; P_{Batt} is the battery power, e.g. the EM power using the electric energy from battery; the λ is the equivalence factor, a parameter that converts the battery power into fuel power. When the equivalence factor λ is determined, an optimisation which is to find the minimum total energy consumption in current time step will be carried out. Then, the optimal power split ratio between fuel power and battery power in current time step can be obtained accordingly. Since the optimisation to find the optimal power split ratio need to be executed each time step, more CPU resource will be used in this case. If the equivalence factor λ is not global optimal, only the local optimal fuel consumption can be achieved in current time step.

Since the power split ratio shall be calculated eventually, an alternative method is to store the pre-calculated optimal cycles, this strategy still has a competitive performance on fuel consumption of WLTP driving cycle and slightly better than the rule-based strategy. This study could be an illustration to prove the robustness of the proposed strategy in a certain degree. In future, more and complex driving cycles, different architectures of the HEV can be used to investigate the robustness and performance of the proposed method in more scenarios. The system identification processes can be improved further, e.g. design the random driving cycles more precisely or use the real driving data logged on the vehicle to capture and cover more real driving conditions. The application of proposed method on real vehicles can also be evaluated.

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Definitions/Abbreviations

ICE - Internal Combustion Engine

EM - Electrical Motor

ECMS - Equivalent Consumption Minimization Strategy

HEV - Hybrid Electric Vehicle

SOC - State of Charge

CS - Charge Sustaining

DP - Dynamic Programming

ISG - Integrated Starter Generator

WLTP - Worldwide Harmonised Light Vehicle Test Procedure

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