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Approximate Dynamic Programming Real-Time Control Design for Plug-In Hybrid Electric Vehicles

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Abstract

A real-time control is proposed for Plug-in Hybrid Electric Vehicles (PHEVs) based on the optimal Dynamic Programming (DP) trajectories in this study. Firstly, the DP is used to solve the Driving Cycle to obtain the optimal trajectories and controls, and the Model-Based Calibration tool (MBC) is used to generate the optimal Maps for the given optimal trajectories. Secondly, a Feedback Energy Management System (FMES) is built with State of Charge (SoC) as the feedback variable, which takes into account the Charge and Discharge Reaction (CDR) of the battery. In order to make full use of the energy stored in the battery, combined with the Charge Deplete-Charge Sustain strategy (CDCS), then the reference SoC is introduced; Finally, a comparative simulation on this real-time controller is conducted against DP, the results show that the fuel consumption of the real-time controller is close to the fuel consumption using DP, and when the driving distance is not known, the controller can maintain the SoC within the desired range, and when the driving distance is known, the SoC can follow the reference SoC well to make full use of the energy stored in the battery.

Keywords

Plug-in hybrid electric vehicle (PHEV), Real-time control, Dynamic programming, Feedback energy management system, CDCS, MBC

1. Introduction

Hybrid electric vehicles use at least two power sources, usually driven by an internal combustion engine associated with a motor, in order to minimize fuel consumption and/or emissions. The energy management of a Plug-in Hybrid Electric Vehicle (PHEV) is often divided into two categories. The first concerns global optimization based on offline simulation. In this case, the vehicle speed is regulated to follow a Driving Cycle using a torque at the wheel controller. The classic is Dynamic Programming (DP) [1, 2, 3, 4, 5]. The main disadvantages of the trajectory-based methods, which limit their direct usage in the real-time energy management systems, include extensive computations and the need for future trip information. A second class of algorithms is the real-time optimal control strategy that can be used to control a vehicle. Several algorithms have been proposed, some of which are based on rules [6, 7] and Equivalent fuel Consumption Minimization Strategy (ECMS) [8, 9, 10, 11, 12, 13], and others are approximate real-time control strategies based on DP [14, 15, 16].

Recently, statistical and deep learning methods have become a popular approach for developing approximate models of complex dynamic systems [17]. A statistical model is fitted based on a set of input-output training data using the least-squares or other error minimization methods, to generate the calibration. The classic application is the Model-Based Calibration tool (MBC).

In general, the optimal trajectories generated by DP are not disorganized but have similarities. To use the optimal DP trajectories for developing a real-time controller, partial trajectories are used first to estimate all trajectories. In this paper, real-time control for PHEV based on Feedback Energy Management System (FEMS) is studied. Real-time implementation has remained a major challenge in the design of complex

m_{f_xf} - Fuel consumption with reference SoC (L/100 km)
D_{real} - Actual distance traveled (km)
D_{cycle} - Estimated Driving Cycle distance (km)
n_{on} - Number of engine starts (—)

Subscripts

wh - Wheel
req - Requirement
gb - Gearbox
elec - Electricity
e - Engine
m - Motor
red - Reducer
opt - Optimal
BT - Battery
rf - Reference
est - Estimate

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