Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 105 (2017) 2672 – 2677

Energy Procedia

The 8th International Conference on Applied Energy – ICAE2016

Plug-In Hybrid Electric Bus Energy Management Based on Stochastic Model Predictive Control

Shanshan Xie[a,b], Jiankun Peng[a,b] , Hongwen He[a,b,]*,

[a] *National Engineering Laboratory for Electric Vehicles, School of Mechanical Engineering, Beijing Institute of Technology, Beijing, 100081, China*

[b] *Collaborative Innovation Center of Electric Vehicles in Beijing, Beijing Institute of Technology, Beijing, 100081, China*

Abstract

Energy management strategy is vital for a plug-in hybrid electric vehicle and in this paper, a strategy based on stochastic model predictive control is proposed. Firstly, Markov Chain Monte Carlo Simulation is used to predict velocity sequences in the 10-second horizon followed by post-processing like average filtering, quadratic fitting, etc. which is meant to moderate fluctuations of the results. The RMSE is controlled around 2.4357 Km/h. Moreover, dynamic programming is adopted to construct a benchmark strategy and also to act as the rolling optimization part of SMPC-based strategy. The results show that the fuel economy of the strategy based on SMPC is around 13 percent worse than that on DP. However, with 14.7 L/100km as fuel consumption, it is still within reasonable ranges.

Peer-review under responsibility of the scientific committee of the 8th International Conference on Applied Energy.

Key words: Energy management strategy; Hybrid electric bus; Markov chain; Model Prediction Control

1. Introduction

Energy management strategy is essential for a hybrid vehicle, plug-in hybrid vehicle included. One of the root reasons is that there are two energy sources for driving the vehicle, the battery packs conserving electricity and the engine that uses petrol in the fuel tank. And the other reason is that the powertrain configuration allows various working modes with different efficiencies. There characteristics offer a great space for energy flow optimization. As this issue can be abstracted as an optimization problem with constraints, many classical or modern optimization algorithms are used to solve it with proper models, hypotheses and constraints [1, 2].

By analyzing and matching the features of energy requirements and the efficiency distributions of main driving components, rule-based control was proposed first. It is robust, has a pretty high calculating efficiency and thus a good real-time performance. However, it cannot achieve fine management and fulfil

* Corresponding author. Tel.: +86 (10) 6891 4842; fax: +86 (10) 6891 4842.
E-mail address: hwhebit@bit.edu.cn.

1876-6102
Peer-review under responsibility of the scientific committee of the 8th International Conference on Applied Energy.
doi:10.1016/j.egypro.2017.03.773

the potentials of the powertrain system. Besides, analytical optimization methods, for example, Pontryagin Minimum Principle (PMP) [3], are adopted. And there are mainly three kinds of numeric ideas to solve this problem, exactly, treating it as a global or a local optimization issue or just optimizing the cost function in the current instant, for instance, equivalent consumption minimization strategy (ECMS) [4,5]. Dynamic programming (DP) [6] can be used to obtain a global optimal result only offline because it needs the total information of driving cycles in advance. Stochastic Model prediction control (SMPC) [7] can search for local optimal control sequences as it is not capable to take the global features of disturbances into consideration. So a reference state trace should be added as supplementary information to assist energy management strategies based on MPC to find a suboptimal consequence. It works in the form of constraints.

In this paper, firstly, an energy management strategy based on DP is implemented in Section 3. In Section 4, velocity sequences in limited horizons are predicted by Markov Chain Monte Carlo Method. Based on the preparations, energy strategy based on SMPC is shown in Section 5. The illustration and comparisons of results of strategies based on SMPC and DP respectively are in Section 6.

2. Powertrain configuration of PHEB

The subject vehicle is a plug-in series-parallel hybrid electric bus (Fig. 1). Its powertrain system allows various energy paths according to different on-off sequences of the components that are included in it. All the parameters of the bus and the driving circumstances can be referred in [8]. The efficiency models of main components are obtained by experiments and stored in the form of map figures. The mass of the bus, which exactly is 10000 kg, is adopted in the calculation process. The driving cycle is the Chinese typical urban driving cycle [8].

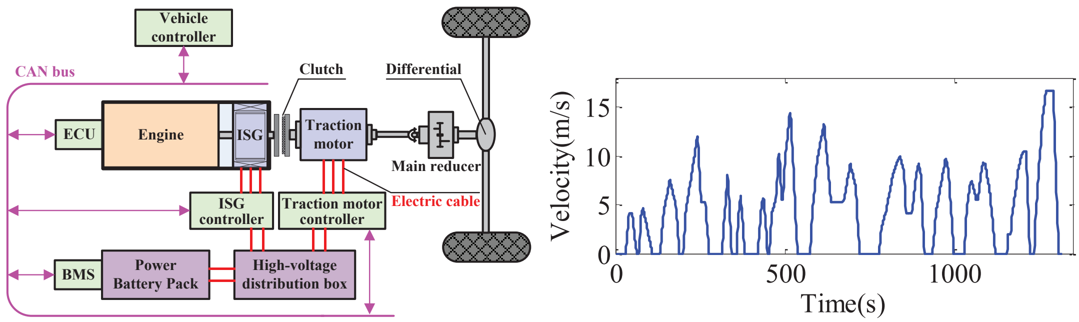

Fig. 1. (a) The powertrain structure of the plug-in series-parallel hybrid electric bus; (b) the typical Chinese urban driving cycle

3. Energy Management Strategy Based on Dynamic Programming

Dynamic programming, which is based on the Bellman optimal principle, is an idea that can be used to achieve global optimum results of certain problems. Firstly it calculates the values of cost functions with the model of the bus and all the inputs and attaches them to the corresponding state and control variables from the end of the discrete sequence of the problem from the end of the discrete sequence of the problem, namely backward, then runs forward to identify the most optimal controlling trace.

According to the degrees of the powertrain structure, there should be five control variables (Table 1). What should be mentioned is that clutch can only be on or off, so the variable related to clutch state is discrete, which means during the DP calculation, no interpolation happens on this variable. There are many hard of soft constraints according to the working potentials of every components that are no more illustrated here. Cost function and constraints of the single state variable are as follows: