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ScienceDirect

Energy Procedia 104 (2016) 378 – 383

Energy Procedia

CUE2016-Applied Energy Symposium and Forum 2016: Low carbon cities & urban energy systems

# Plug-In Hybrid Electric Bus Energy Management Based on Dynamic Programming

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**Abstract**

An energy management strategy based on dynamic programming for a plug-in serial-parallel hybrid electric bus is proposed. The sets of comprehensive cost function, five control variables and mesh accuracies are illustrated. Then the fuel economy is discussed, followed by the sensitivity analysis of this strategy on different lengths of driving cycle input and dissimilar control variable settings. It can be concluded that scaling the length of driving cycle and battery capacity have little effect on control laws output while optimum control variable settings should combine exact characters of driving cycles and driving components of the bus.


Peer-review under responsibility of the scientific committee of the Applied Energy Symposium and Forum, CUE2016: Low carbon cities and urban energy systems.

*Key words:* Energy management strategy; Dynamic programming; Hybrid electric bus

## 1. Introduction

There are two sources of power for hybrid vehicles and all possible working modes have different levels of efficiency. Therefore, it is important to optimize the power distribution of the vehicle energy management system. Energy management strategies are widely researched in recent years [1]. Dynamic programming (DP) [2, 3] is one of the algorithms that can be used to search for global optimal results, which means it can potentially reduce the cost function to the minimum.

But the major problem with DP is its huge computation burdens. Thus the state and control variables cannot be too complicated and the mesh accuracies are also limited, restricting the uses of DP on real-time applications. However, the excellent computation results of DP are often used as the baselines of results of

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1876-6102 
Peer-review under responsibility of the scientific committee of the Applied Energy Symposium and Forum, CUE2016: Low carbon cities and urban energy systems.
doi:10.1016/j.egypro.2016.12.064

other energy management strategies [4]. Occasionally they are also used as reference to derive control rules to be used online [5, 6]. But all of these studies only focus on series or parallel hybrid vehicles [7]. The series-parallel configuration is relatively rarely studied. Therefore, it is the purpose of this paper to propose an energy management strategy based on DP for a plug-in serial-parallel hybrid electric bus (PHEB).

In the next section, the basic information of this bus is provided. The energy management strategy based on DP is illustrated in Section 3. In Section 4, the reasonability of the optimum control laws is analyzed from two angles, working modes and the distribution of working points of the main components. Section 5 explores the sensitivities of this strategy on different settings before conclusions are drawn in the final section.

## 2. Powertrain structure of PHEB

The bus that is studied in this paper is a plug-in series-parallel hybrid electric vehicle (Fig. 1) [8]. All the original data used to abstract models of components is obtained by experiments, stored in the form of discrete points and shown in map figures or line graphs. Battery model is Rint model.

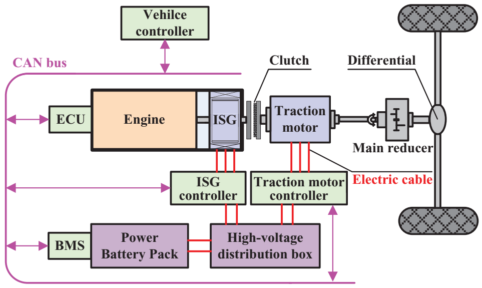


Fig. 1. The powertrain structure of the plug-in series-parallel hybrid electric bus

## 3. Energy Management Strategy Based on Dynamic Programming

The objective function, namely cost function, is normally defined only in terms of fuel consumption. But this paper takes both fuel and electricity consumption into consideration. To a certain extent, the marketing prices of petrol and electricity per unit can reflect the cost of environment and resources, thus we use the ratio of the unit prices of these two kinds of energy to calculate the equivalent fuel consumption of a certain amount of electricity. The ratio is $\Omega = 5.56/1.3332 = 4.1704$. Cost function and constraints are as follows:

$$\begin{cases} \min\limits_{u_k \in U_k} \left( \sum\limits_{k=0}^{N-1} \Delta m_f(u_k,k) + \Omega \times \sum\limits_{k=0}^{N-1} \Delta P_b(u_k,k) \right) \\ SOC_{k+1} = SOC_k + f_k(SOC_k, u_k) \\ SOC_0 = 1 \\ SOC_N \in [0.3, 0.302] \end{cases} \tag{1}$$

The mesh accuracy can significantly affect the calculating burden of the energy management strategy based on dynamic programming, which deserves further discussion. In all the control variables, the clutch state can only be “on” or “off”, so the mesh accuracy is fixed. As for the other four variables, the mesh accuracies should be set according to how significantly they affect the corresponding component efficiencies: the more significantly the effect is, the thinner the grid should be. For example, according to