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# An energy management approach of hybrid vehicles using traffic preview information for energy saving

Chunhua Zheng [a], Guoqing Xu [b,c,*], Kun Xu [a,d], Zhongming Pan [a,d], Quan Liang [e]

[a] Shenzhen Institutes of Advanced Technology, Chinese Academy of Sciences, 1068 Xueyuan Avenue, Shenzhen University Town, Shenzhen 518055, China
[b] Department of Electrical Engineering, Tongji University, 4800 Caoan Road, Shanghai 201804, China
[c] Department of Mechanical and Automation Engineering, The Chinese University of Hong Kong, Hong Kong 999077, Hong Kong, China
[d] Shenzhen College of Advanced Technology, University of Chinese Academy of Sciences, 1068 Xueyuan Avenue, Shenzhen University Town, Shenzhen 518055, China
[e] Sinopoly New Energy System Co., Ltd, 108 Changda Road, Yuhang Economic and Technology Development Zone, Hangzhou, China

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ABSTRACT

The traffic preview information is very helpful for hybrid vehicles when distributing the power requirement of the vehicle to power sources and when determining the next driving route of the vehicle. In this research, an energy management approach for hybrid vehicles is proposed, which optimizes the vehicle velocity profile while minimizing the fuel consumption with the help of the traffic preview information, so that a further energy saving for hybrid vehicles can be achieved. The Pontryagin's Minimum Principle (PMP) is adopted on the proposed approach. A fuel cell hybrid vehicle (FCHV) is selected as an example, and the proposed energy management approach is applied to the FCHV in a computer simulation environment for the offline and online cases respectively. Simulation results show that the fuel economy of the FCHV is improved by the proposed energy management approach compared to a benchmark case where the driving cycle is fixed and only the hybrid power split (allocation) ratio is optimized. The proposed energy management approach is useful especially for the autonomous hybrid vehicles.


## 1. Introduction

The energy management strategy is a major research topic of hybrid vehicles, given that it directly influences the fuel economy of hybrid vehicles. Up to now, several types of energy management strategies have been investigated for hybrid vehicles including heuristic concept-based energy management strategies [1–3] and optimal control theory-based energy management strategies [4–7]. These energy management strategies were usually evaluated on some specific vehicle driving cycles. In reality, however, the driving cycle is not fixed, and it is dependent on the traffic condition and the driver's behavior. Consequently, energy management strategies accompanied by the prediction of the future driving cycle were developed for hybrid vehicles. The prediction method of the vehicle driving cycle can be divided into two groups: one is based on the past driving information [8,9]; the other is based on the vehicle telemetry such as the Global Positioning System (GPS), the Intelligent Transportation System (ITS). The former group depends on the number of characteristic parameters of the driving cycle, thus the characteristic parameters should be selected as many as possible in order to guarantee the accuracy. This will increase the complexity. On the other hand, the latter group is a direct method and will be the best solution if the vehicle telemetry provides useful driving condition information to the drivers.

Previous research [10] presented that adjusting the vehicle velocity profile according to the traffic preview information can substantially improve the fuel economy of vehicles. For hybrid vehicles, if the traffic preview information is obtained, the vehicle driving route and the power split ratio between power sources can be optimized at the same time, which contributes to further improvements in the fuel economy. Until now, few researchers have considered the adjustment of the vehicle driving route when developing energy management strategies of hybrid vehicles based on the traffic preview information. Additionally, there are some points to be further improved in the existing research on adjusting the vehicle velocity profile. In the research [10], the predicted vehicle velocity profile is modified instantaneously in order to minimize the stop-start behavior of the vehicle, while it is guaranteed that the vehicle reaches the desired location at the desired time, so that the fuel economy can be further improved. This modification is effective because it minimizes the vehicle accelerations.

* Corresponding author at: Department of Electrical Engineering, Tongji University, 4800 Caoan Road, Shanghai 201804, China. Tel.: +86 755 8639 2147; fax: +86 755 8639 2299.
*E-mail address:* gq.xu@siat.ac.cn (G. Xu).

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But, it also has the effect of decreasing the regenerative braking energy. Thus, in their later research [11], the vehicle velocity modification algorithm is slightly upgraded in order to capture more regenerative braking energy. However, the above two studies still leave room for improvement of the fuel economy, as the modification of the vehicle velocity profile is not optimized. An ideal energy management strategy of hybrid vehicles should not only optimize the power split ratio but also optimize the vehicle driving route based on the traffic preview information. In the subsequent research [12] of [10,11], the two items are optimized at the same time by a Sequential Quadratic Programming (SQP) using the traffic preview information. In the above three studies, the specific traffic preview information should be given by the form of vehicle velocity versus time or the form of vehicle velocity versus distance. In reality, however, it is difficult to provide such specific traffic preview information. In the research [13], a control approach which combines the Dynamic Programming (DP) and the Pontryagin's Minimum Principle (PMP) is proposed. This approach optimizes the power split ratio and the vehicle velocity simultaneously without the specific traffic preview information above. However, this approach takes long calculation time, given that it partially adopts the DP. This feature will definitely affect the implementation of the approach.

In this research, an energy management approach of hybrid vehicles is proposed, which optimizes both the power split ratio and the vehicle driving route simultaneously based on the traffic preview information. The PMP is adopted in this research. Here, the specific traffic preview information is not necessary. Instead, the information on the maximum and the minimum velocity limitations along the prediction period is needed. Fig. 1 illustrates the concept of the proposed energy management approach. Here, the maximum and minimum velocity limitations are able to be obtained from the traffic flow information based on the GPS, ITS, and other devices, in which the distance information to adjacent vehicles is already reflected. The vehicle needs to find the optimal driving route between the velocity limitations while guaranteeing the minimum fuel consumption. The vehicle is also required to reach the desired destination at the desired time. Owing to the use of the PMP, the proposed approach instantaneously provides the optimal solution with a short calculation time, thus it has the possibility to be used in the real-world driving. The formulation of the optimization problem is introduced and the proposed energy management approach is implemented in a computer simulation environment for the offline and online cases in this research. Simulation results of the proposed approach are presented and compared to those of a strategy in which only the power split ratio is optimized based on the PMP assuming that the future driving cycle is provided a priori.

The proposed energy management approach is related to the vehicle driving route optimization. In general, however, the vehicle velocity is directly controlled by the driver. Currently, intelligent vehicles and environmentally friendly vehicles are the two big issues in the automotive field. The proposed energy management approach considers the two issues together, thus it is especially suitable for autonomous hybrid vehicles or it can also be used in the assist control of the power system and braking system of semi-autonomous hybrid vehicles.

This paper is organized as follows: Section 2 introduces the proposed energy management approach on the basis of a basic strategy; Section 3 deals with applications of the proposed approach for offline and online cases and presents the simulation results; the discussion and conclusion are drawn from this research in the final section.

## 2. Optimization problem formulation and the proposed energy management approach

A fuel cell hybrid vehicle (FCHV) is selected as the objective hybrid vehicle in this research, in which a fuel cell system (FCS) and a battery are the two power sources. The FCS is the main power source while the battery is the secondary power source, and they power the electric motor together. The battery can be charged by the FCS in some cases and recover the regenerative braking energy. The configuration and the energy flow of the FCHV can be found in Appendix A at the end of this paper. The total mass of the FCHV is 1700 kg here. A 62 kW FCS and a 1.95 kW h battery are the two power sources of the FCHV. Further information on this FCHV can be found in our previous research [14] and in Appendix A. This FCHV will be used throughout this paper.

The PMP is adopted on the proposed energy management approach. The proposed energy management approach is introduced by comparing it to a strategy which only optimizes the power split ratio based on the PMP assuming that the future driving cycle is provided in advance. Here, the power split ratio indicates the percentage of the main power source's power in the total power requirement. For convenience, the latter strategy is defined as the basic strategy in this research.

### 2.1. The basic strategy

The basic strategy was studied by some researchers and can also be found in our previous research [15,16]. In this strategy, the control objective is to optimize the power split ratio between power sources in an FCHV when the entire driving cycle is given in advance, so that the fuel consumption is minimized. There is

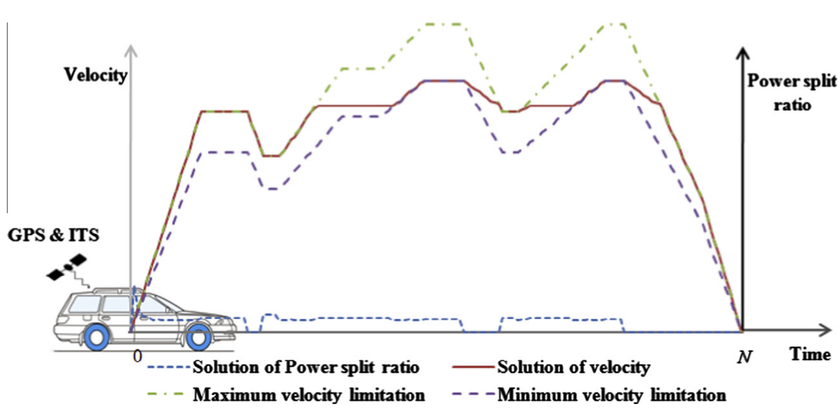


**Fig. 1.** Concept of the proposed energy management approach.