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Adaptive Power Management Strategy for a Four-Mode Hybrid Electric Vehicle

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Abstract

A conventional vehicle propelled with only the internal combustion engine (ICE) is not easy to enhance the fuel economy due to the wide range operation requirement of the powertrain. However, a hybrid electric vehicle (HEV) which consists of an ICE and one or multiple electric motors can effectively improve the efficiency of the powertrain. In this paper, we propose an adaptive power management strategy (PMS) based on the equivalent fuel consumption minimization strategy (ECMS) for a four-mode HEV. The four-mode HEV which consists of an ICE and two motors provides four modes of operation, including electric vehicle (EV) mode, range extended (RE) mode, hybrid mode, and engine mode. The adaptive PMS is designed for charge sustaining such that the state of charge (SOC) can be maintained at a certain value. A self-organizing fuzzy controller (SOFC) is employed to adaptively adjust the equivalence factor of electric energy consumption based on the SOC deviation and the change of SOC deviation. An instantaneous cost function which consists of the fuel consumption of ICE and the equivalent fuel consumption of the battery is minimized to obtain the optimum power distributions of the ICE and two motors. Simulation results show that the adaptive PMS can effectively improve the fuel economy for different driving cycles.

Keywords: hybrid electric vehicle; equivalent fuel consumption minimization; adaptive power management strategy

1. Introduction

A hybrid electric vehicle (HEV) consists of an internal combustion engine (ICE), one or multiple electric motors, and a battery pack. Powertrain electrification can reduce the fuel consumption by operating ICE in the high efficiency region. However, the increased configuration complexity poses a challenge for

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efficiently controlling the power flows between multiple power sources. Various power management strategies (PMS) have been investigated to provide better fuel economies for HEVs.

The PMS of HEV can be classified into three types. The first type is rule-based control [1] which is commonly designed based on rules extracted from engineers' expertise. The second type is the equivalent fuel consumption minimization strategy (ECMS) which employs static optimization to obtain the local minimization of an instantaneous cost function [2]. The third type is the global minimization over a time horizon based on dynamic programming [3] which can offer the performance upper bound for benchmarking other control strategies. Sun et al. [4] proposed an adaptive-ECMS combined with a velocity predictor to provide temporary driving information for real-time adaptation of the equivalence factor (EF). Model predictive control (MPC) can be employed to design PMS [5]. Borhan et al. [6] formulated a nonlinear and constrained optimal control problem for the PMS design. MPC is then utilized to obtain the power split between the ICE and electrical motors.

In this paper, we design an adaptive PMS for a four-mode HEV based on ECMS. A self-organizing fuzzy controller (SOFC) is employed to adaptively adjust the equivalence factor of electric energy consumption based on the SOC deviation. An instantaneous cost function of the fuel consumption of ICE and the equivalent fuel consumption of the battery is minimized to obtain the optimum power distributions of the ICE and two motors. The remainder of the paper is organized as follows. In Section 2, the configuration of a four-mode HEV is introduced. The proposed adaptive PMS is presented in Section 3. Simulation results are illustrated in Section 4, and conclusions are presented in Section 5.

2. Modeling

The system configuration of the four-mode HEV [7] as shown in Fig. 1(a) uses two clutches, C_0 and C_1, to change the operating modes. The ICE and the coaxial integrated starter generator (ISG) transfer the mechanical power to the output shaft via the clutch C_0. A traction motor (TM) transfers the mechanical power to the output shaft via the plenary gear set and the clutch C_1. The first mode is the electric vehicle (EV) mode using only TM with C_1 closed. The second mode is the range extended (RE) mode using ICE and ISG as genset with C_0 open, and TM for driving with C_1 closed. The third mode is the hybrid mode using ICE, ISG and TM with C_0 and C_1 closed. The fourth mode is the engine mode using only ICE with C_0 closed. The engine of the four-mode HEV is a 2.0 liter ICE with turbo charger. The rated powers of the TM and ISG are 50kW and 25kW, respectively.

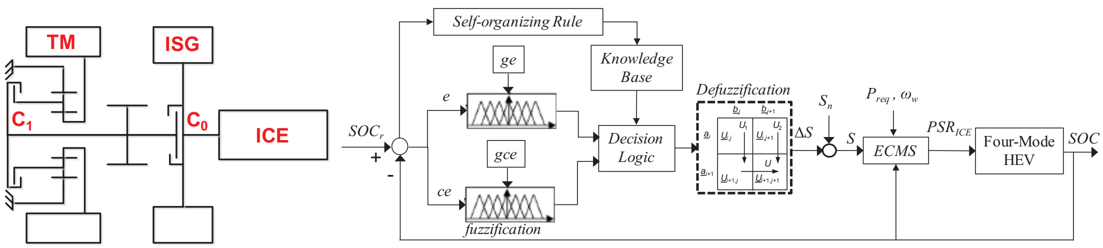

Fig. 1. (a) System configuration of the four-mode HEV; (b) Proposed adaptive power management strategy

3. Control Strategy

3.1. Equivalent Fuel Consumption Minimization Strategy (ECMS)