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A real time fuzzy logic power management strategy for a fuel cell vehicle

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ABSTRACT

This paper presents real time fuzzy logic controller (FLC) approach used to design a power management strategy for a hybrid electric vehicle and to protect the battery from overcharging during the repetitive braking energy accumulation. The fuel cell (FC) and battery (B)/supercapacitor (SC) are the primary and secondary power sources, respectively. This paper analyzes and evaluates the performance of the three configurations, FC/B, FC/SC and FC/B/SC during real time driving conditions and unknown driving cycle. The MATLAB/Simulink and SimPowerSystems software packages are used to model the electrical and mechanical elements of hybrid vehicles and implement a fuzzy logic strategy.

1. Introduction

The need to minimize noxious CO_2 and greenhouse gas emissions has led to an increase in the use of hybrid vehicles in recent years. These vehicles include thermal hybrid vehicles, electrical vehicles equipped with a battery, and fuel cell hybrid vehicles.

Progress has been made in fuel cell modeling and characterization, and also in understanding the static converters that interface with the fuel cell during charging. Nevertheless, studies of energy management and optimization are still at an early stage. It is challenging to develop an energy management strategy for a hybrid vehicle supported by a storage device such as a battery or a supercapacitor. Regardless of the route, the available power must be distributed among the various components to minimize hydrogen utilization and increase lifetime.

Several energy management strategies have been suggested to control the distribution of power between the two sources and the load. Ref. [1] presents the energy management system based on an equivalent consumption minimization strategy (ECMS). Ref. [2] develops a real time optimal energy management strategy based on the determined dynamic programming (DDP) strategy. Refs. [3–6] propose a fuzzy logic control system.

Some references have proposed using a fuzzy logic controller energy management for fuel cell electrical vehicle. Ref. [3] lists some advantages of this method.

Ref. [3] proposes a fuzzy logic implemented in the ADVISOR environment for FC/B and FC/B/SC vehicles to improve the fuel economy and increase the distance traveled. This method results in better fuel economy and driving cycle conditions but the battery or supercapacitor SOC information are not presented in this paper.

The Ref. [4] proposes a fuzzy logic control system for power management and uses a known city driving cycle (UDDS) to determine the optimal fuel cell and battery power on a hybrid bus. The results of this proposed method show a good power distribution between the mini-bus power sources and the required power. Also, the battery SOC is maintained bounded. In this study, the battery SOC results show that the SOC increases in repetitive braking during the latest part of UDDS drive cycle.

Ref. [5] presents a fuzzy logic based control methodology. This proposed strategy is based on a priori knowledge of driving cycle to design the degree of hybridization and also membership functions of the fuzzy controller using optimization problem witch maximize fuel cell hybrid vehicle efficiency. The major inconvenient of this proposed strategy is that it needs a known driving cycle, so it is not applied for real time control. This proposed strategy results is compared using fuzzy logic control with fixed membership functions and optimized degree of hybridization. The simulation results shows that this proposed strategy improve the system efficiency, but the optimal degree of hybridization is not sensitive of different driving cycles.

Ref. [6] introduces the wavelet fuzzy logic strategy to control and distribute the required power from the power sources to the load.

In this paper, the fuzzy logic power management strategy is implemented in a hybrid vehicle with multiple power sources.

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The fuel cell is the primary power source and the secondary power sources are the battery and supercapacitor.

This paper is structured in next four sections. The Section 2 describe the proposed power management strategy. Section 3 presents dynamic models of different system component. Section 4 presents a simulation results and Section 5 presents the conclusions.

2. Proposed power management strategy

In standard power management based on fuzzy logic controller, the load power required by the vehicle must be met during the drive cycle. The power management strategy should compute the fuel cell power and the secondary source power and respect the dynamic power source restrictions. The load power required during a drive cycle and the states of charge of the secondary power sources are used in the fuzzy logic controller. The results presented in literatures show that the battery SOC increases during multiple and consecutive braking, knowing that the standard UDDS driving cycle takes 1400 s. The Fig. 1 shows the problem of increase the battery SOC during multiple braking.

The proposed approach has to manage the power required and sources, depending on the unknown driving cycle. As the battery charged, it provides the power required and the fuel cell is at minimal power. This approach will protect the battery from overcharging during the repetitive braking energy accumulation. On the other hand, the effects of repetitive braking are not adopted by approaches in the literatures.

The power management strategy is implemented to compute and provide power reference signals to fuel cells, motors, secondary power sources (battery, supercapacitor) and DC/DC converters. A fuzzy logic controller map has two inputs (P_{Dem}, SOC) and one output (P_{FC}) (Fig. 2). The logic rules according to the controller inputs and output show that if the battery SOC is low, the fuel cell has to charge the battery, and then the fuel cell power is high. In the other case, if the battery SOC is high, the fuel cell power is minimum regardless the required power. The case where battery SOC is medium, the fuel cell power output has to be adapted according to the power required input (Table 1). The membership functions is presented in Fig. 3. The vehicle parameters and constrains are shown in Table 2 and Table 3.

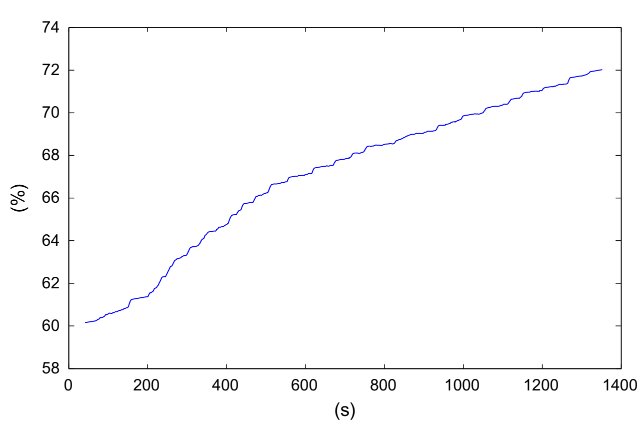

Fig. 1. Battery state of charge for standard controller.

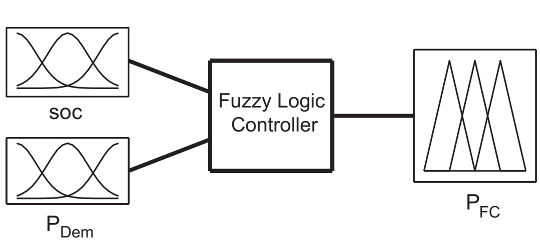

Fig. 2. Fuzzy logic controller.

Table 1
Rule base of fuzzy logic controller.

P_{dem}/SOC	Low	Medium	High
TooLow	TooHigh	TooLow	TooLow
Low	TooHigh	Low	TooLow
Medium	TooHigh	Medium	TooLow
TooHigh	TooHigh	TooHigh	TooLow

Table 2
Vehicle parameters.

Dimensions	Overall length (in.)	190.3
	Overall width (in.)	72.7
	Overall height (in.)	57.8
	Tread (front/rear, in.)	62.2/62.8
	Wheelbase (in.)	110.2
Weight	Vehicle weight (kg)	1625
Occupancy	Number of occupants	4
	Maximum speed (mph)	100

Table 3
System constraints.

Fuel cell	kW	$0.4 \leqslant P_{FC} \leqslant 100$
Battery	kW	$-25 \leqslant P_{Batt} \leqslant 25$
SOC	%	$40 \leqslant SOC \leqslant 80$

3. Component modeling

Hybrid vehicles use at least one secondary power source due to its reversible contribution of additional power, thus reducing the hydrogen consumption in the fuel cell. The secondary power source recovers energy during vehicle braking. The most frequently used secondary power sources are batteries or supercapacitors.

3.1. Fuel cell model

The fuel cell is an electrochemical device that obtains electrical energy by a chemical reaction. The electrical energy is produced without emitting any gas. Fuel cells have significant advantages, including no emissions, high efficiency and high performance.

Fuel cells operate at high power, leading to their application to automobiles and power distribution. The fuel cell is able to directly convert hydrogen energy without using combustion and to operate at low temperatures. The voltage of the fuel cell varies according to the load [7].

$$V_{fc} = N_{cell} V_{cell} \quad (1)$$

The SimPowerSystems library in Simulink contains a dynamic fuel cell model [8]. The pressure, temperature, flow rates and compositions of fuel and air during the operation of the fuel cell stack can be measured in real time using the fuel cell model. The output fuel cell voltage V_{fc} is calculated by multiplying the number of cells N_{cell} and the cell voltage output V_{cell} (Eq. (1)). The air and hydrogen flow rates are calculated by Eqs. (2) and (3) [8].