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FUEL ECONOMY EVALUATION OF FUEL CELL HYBRID VEHICLES BASED ON OPTIMAL CONTROL

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ABSTRACT−The fuel economy of a fuel cell hybrid vehicle (FCHV) depends on its power management strategy because the strategy determines the power split between the power sources. Several types of power management strategies have been developed to improve the fuel economy of FCHVs. This paper proposes an optimal control scheme based on the Minimum Principle. This optimal control provides the necessary optimality conditions that minimize the fuel consumption and optimize the power distribution between the fuel cell system (FCS) and the battery during driving. In this optimal control, the final battery state of charge (SOC) and the fuel consumption have an approximately proportional relationship. This relationship is expressed by a linear line, and this line is defined as the optimal line in this research. The optimal lines for different vehicle masses and different driving cycles are obtained and compared. This research presents a new method of fuel economy evaluation. The fuel economy of other power management strategies can be evaluated based on the optimal lines. A rule-based power management strategy is introduced, and its fuel economy is evaluated by the optimal line.

KEY WORDS : FCHV(Fuel Cell Hybrid Vehicle), Fuel economy evaluation, Optimal control, Optimal line, Rule-based strategy

NOMENCLATURE

P_{stack} : stack power (W)
N_{cell} : number of cells
V_{cell} : cell voltage (V)
I_{stack} : stack current (A)
P_{fcs} : FCS net power (W)
P_{aux} : power consumption of auxiliary components (W)
$\dot{m}_{h2}$: fuel consumption rate (g/s)
M_{h2} : molar mass of hydrogen (g/mol)
n : number of electrons acting in the reaction
F : Faraday constant (C/mol)
λ : hydrogen excess ratio
V : open circuit voltage (V)
R : internal resistance (Ohm)
Q_{bat} : battery capacity (C)
P_{bat} : battery power (W)
J : performance measure (g)
t_0 : initial time (s)
t_f : final time (s)
p : costate (g)
H : Hamiltonian (g/s)
η_{fcs} : efficiency of the FCS

FCHV : fuel cell hybrid vehicle
FCS : fuel cell system
OCV : open circuit voltage
SOC : state of charge
LHV : lower heating value

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1. INTRODUCTION

FCHVs have become a major topic of interest among researchers in academia and in the automotive industry. The power management strategy is significant for an FCHV because it directly affects the fuel consumption. Several types of power management strategies have been developed for FCHVs, including optimal or near-optimal control strategies based on optimal control theory (Bernard *et al*., 2006; Kim and Peng, 2007) and rule-based algorithms (Ehsani *et al*., 2010). Among them, optimal control based on the Minimum Principle is applied to this study. This optimal control minimizes the fuel consumption and optimizes the power distribution between the FCS and the battery by providing the necessary optimality conditions. Some researchers have studied this optimal control for FCHVs and also for general hybrid electric vehicles (Bernard *et al*., 2010; Delprat *et al*., 2004). However, they did not apply optimal control to an evaluation of the fuel economy. The result of optimal