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OPTIMAL ENERGY DISTRIBUTION OF MULTI-ENERGY SOURCES IN FUEL-CELL ELECTRIC BUS USING LONG SHORT-TERM MEMORY

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ABSTRACT–Environmental issues such as air pollution and abnormal climate are global concerns. To overcome these problems, the automobile industry is prioritizing the development of eco-friendly vehicles that reduce greenhouse gas emissions. Among these, fuel-cell electric vehicles (FCEVs) use hydrogen as a fuel and do not emit exhaust gas and their higher mileage and shorter fuel charging time compared to electric vehicles make them promising next-generation eco-friendly vehicles. However, conventional energy management strategies have not effectively implemented both real-time capability and optimal energy distribution in FCEVs. To address these issues, a powertrain utilizing multi-energy sources is utilized, and a real-time energy control strategy based on long short-term memory (LSTM) is proposed. The training data for LSTM is obtained from the results of dynamic programming, utilizing six-city bus driving cycles, and the Braunschweig city driving cycle is chosen for test simulation. As a result, the LSTM prediction performance is evaluated, resulting in the development of an effective algorithm for real-time energy management of multi-energy sourced FCEVs.

KEY WORDS : Fuel-cell electric bus, Ultra-capacitor, Dynamic programming, Long short-term memory, Energy management strategy, Hybrid energy storage system

NOMENCLATURE

F_t : tractive resistance, N
P_{veh} : required vehicle power, W
$P_{mot,mech}$: mechanical motor power, W
$P_{mot,elec}$: electrical motor power, W
N_{mot} : rotational speed of the motor, rad/s
T_{mot} : torque of the motor, Nm
η_{mot} : efficiency of the motor
i_{gear} : efficiency of the gear
R_{tire} : tire radius, m
$V_{b,oc}$: open circuit voltage of the battery, V
V_b : terminal voltage of the battery, V
I_b : current of the battery, A
$R_{b,i}$: internal resistance of the battery, ohm
P_b : power of the battery, W
$SoC_{b,init}$: initial state of charge of the battery, %
C_b : rated capacity of the battery, Wh
Q_{init} : initial charge of the capacitor, Q
$Q_{\max}$: maximum charge of the capacitor, Q
C_{uc} : rated capacitance of the ultra- capacitor, Wh
I_{uc} : current of the ultra-capacitor, A
$V_{uc,oc}$: open circuit voltage of the ultra-capacitor, V
P_{uc} : power of the ultra-capacitor, W
P_{fc} : net power of the fuel cell, W

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1. INTRODUCTION

Carbon dioxide reduction has become an important issue in the automotive industry. According to the International Energy Agency, as of 2015, the transportation sector accounted for 24 % of total carbon dioxide emissions, and countries worldwide are strengthening regulations regarding carbon dioxide emissions. The United States plans to increase carbon dioxide emission regulations by 36 % by 2025, based on 2017 figures. Additionally, the EU plans to increase carbon dioxide emission regulations by 55 % by 2030, based on 2015 figures. The California Air Resources Board, which primarily determines global vehicle emission