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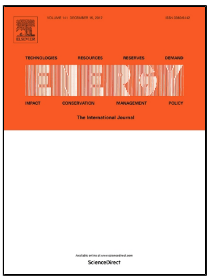

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Hierarchical control strategy with battery aging consideration for hybrid electric vehicle regenerative braking control

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Abstract

Regenerative braking is a key technology for hybrid electric vehicles (HEVs) to improve fuel economy, and it is a multi-objective control problem, which should ensure vehicle braking safety, recover more energy, and protect components from aging. As is known, battery is the most sensitive component in hybrid powertrain, so a large recover current can cause damage to the battery and reduce its life. However, the damage to is usually ignored in regenerative braking. Therefore, this paper proposed a hierarchical control strategy with battery aging consideration to solve the problem. In the up-level controller, the control targets are to recover more energy and minimize aging of the battery in general braking mode, and ensuring the vehicle braking safety in emergency braking mode at the same time. The low-level controller receives the commands of the up-level controller, and controls the pneumatic braking system and the electric motor (EM). The constraints of maximum EM torque and maximum battery charging power are set to protect the EM and the battery. Simulation tests are designed to indicate the effects of regenerative braking on battery aging and the control effectiveness of the proposed method, and controller-in-the-loop tests are carried out to verify the real-time calculation performance.

Keywords

Plug-in hybrid electric vehicle, regenerative braking, battery aging, model predictive control

1. Introduction

WITH the dwindling fossil fuel reserves and enhanced public consciousness of environment issues, automobiles are required to be more efficient and environment-friendly [1]. Hybrid electric vehicles (HEVs) have great potential to reduce energy consumption and pollution emission by enhancing the engine's working efficiency [2]. Among all the technologies of HEV, regenerative braking is the most effective approach to enhance fuel economy [3].

Regenerative braking's potential in recovering energy depends on the structure of braking system and the control strategy. The structure of a regenerative braking system can be divided into two kinds. One is series structure, where the braking pedal force is decoupled with the mechanical braking torque, and the whole braking torque is distributed to mechanical braking system and regenerative braking system according to control strategies. Another is parallel structure, where braking pedal force is not decoupled with the mechanical braking torque and the regenerative braking torque is additional on the wheels [4]. Obviously, the series structure has more freedom to design control strategies, and more braking energy can be recovered, so many literatures have focused on it. Ko et al. designed a new braking system to improve the efficiency of energy recovery and decrease the cost of transformation, in which an electronic wedge braking system was equipped on front wheels and a hydraulic braking system was equipped on rear wheels [5]. Yang et al. designed a new pressure coordinated control system to achieve regenerative braking and traditional ABS braking at the same time [6]. Zhou et al. designed a novel electromechanical braking system to replace the

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