

Study on a Predictive Battery Charging Control System for Series Hybrid Electric Vehicles Using Gradient Information

Yuhi Abe ¹⁾ Takahiro Shimizu ¹⁾ Hyuga Chujo ¹⁾ Mai Shinkawa ¹⁾ Jin Kusaka ¹⁾

*1) Waseda University, Graduate School of Creative Science and Engineering, Department of Modern Mechanical Engineering
Postal Code 169-8555, Room 226, Building 58, 3-4-1 Okubo, Shinjuku-ku, Tokyo, Japan*

KEY WORDS: EV and HV system, State of charge, Energy regeneration, Predictive control (A3)

In recent years, stricter fuel economy and emission regulations worldwide have accelerated the development and widespread adoption of hybrid electric vehicles (HEVs). These vehicles employ an energy management system (EMS) that governs energy distribution between the engine and motor, as well as engine start/stop control. Conventionally, fuel economy and emissions have been evaluated using prescribed driving cycles such as JC08 and WLTC. However, indoor chassis-dyno tests based on these cycles can deviate significantly from real-world driving conditions, and Real Driving Emissions (RDE) testing has therefore attracted increasing attention. The purpose of this study is to propose a predictive battery charging control system using road gradient information and to verify its fuel economy improvement using a vehicle model identified from real driving data.

A series HEV model was used in this study, consisting of an engine fuel consumption map, a motor efficiency map, and a battery equivalent circuit model (OCV and internal resistance). The baseline engine control starts and stops the engine based on an SOC-dependent power threshold. The test route assumes suburban driving with steep and continuous uphill and downhill sections, with a total driving distance of 27 km and an altitude difference of 981 m.

The proposed control system is built on gradient information of the entire driving route. The core policy is to actively discharge the battery during uphill driving to reduce fuel consumption, and to secure sufficient charging headroom in the battery during the subsequent downhill section to maximize regenerative energy recovery. The driving force acting on the vehicle and the recoverable regenerative energy are formulated as:

$$F_{drv} = Ma + \mu Mg + \frac{1}{2} C_d A \rho V^2 + Mgsin\theta \quad (1)$$

$$E_{rege} = \sum_i Mgsin\theta_i \cdot x_i = \int Mgsin\theta \cdot v \, dt \quad (2)$$

If the SOC falls below the lower limit (15%), the engine is forced to start regardless of the predictive estimate. Otherwise, the sum of predicted regenerative energy and available battery headroom over the forward section is compared with the remaining driving energy demand. If the demand can be met solely by the current battery capacity and regenerated power, the engine is switched off.

As shown in Fig. 1, the SOC at the end of the uphill section (900 s) was reduced from 63.67% (baseline) to 28.57% with the proposed control. This difference of 35.1 percentage points corresponds to 1,820 kJ of battery capacity secured in advance for regeneration. As a result, cumulative regenerated energy increased from 3,204 kJ to 6,056 kJ (+88.9%), and fuel economy improved from 12.79 km/L to 14.06 km/L (+9.93%). The key contributing factors are reduced fuel consumption through prioritized battery use during uphill driving, and suppression of unnecessary engine starts in short positive-gradient sections by anticipating the subsequent downhill. On the other hand, the SOC variation range widened from 46.0% to 71.5%, and the duration of high-C-rate charge/discharge operation increased substantially, suggesting that the proposed control may impose greater stress on the battery. Future work will focus on evaluating the system under RDE-compliant driving conditions and developing an adaptive algorithm capable of handling real-time route changes during urban driving.

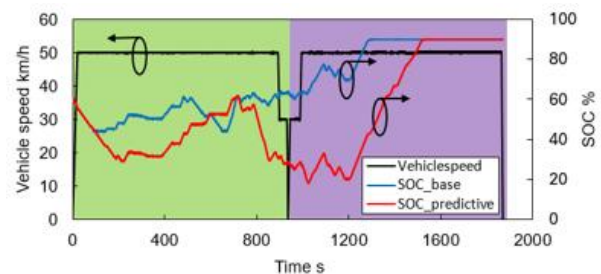


Fig.1 Time history of SOC and vehicle speed