Advances in Automobile Engineering

Extended Abstract

Evaluating emissions and sensitivity of economic gains for series plug-in hybrid electric vehicle powertrains for transit bus applications

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Abstract

From the design space explored for series architecture plug-in hybrid electric vehicle transit buses by the authors, one powertrain and control design is selected to provide maximum benefit to investment ratio. Sensitivity analysis is performed for this powertrain configuration. Vehicle parameters (including vehicle mass, coefficient of drag, coefficient of rolling resistance), usage parameters (drivecycle, annual vehicle miles traveled, number of recharges in a day, recharge current, and battery temperature), and economic parameters (fuel price, motor price, and battery price) are varied to understand their effect on the number of required battery replacements, net present value, payback period, and fuel consumption reduction. It is shown that battery temperature has the most significant impact, particularly on the number of battery replacements and net present value and, as such, must be well controlled in practice. It is shown that to maintain the battery at 20C, for ambient temperatures between 25C and 45C, 0.8–1.8% excess fuel is required across all drivecycles for the considered plug-in hybrid electric vehicle transit bus powertrain configuration. In addition, the wellto-wheel emissions of criteria pollutants resulting from the usage of this plug-in hybrid electric vehicle transit bus in Indiana and California are calculated and compared with the conventional transit bus, using the GREET (Greenhouse Gases, Regulated Emissions and Energy Use in Transportation) Model. With a single over night charge, the plug-in hybrid electric vehicle transit bus operating in either Indiana or California produces 50% less CO_2 and other greenhouse gases as compared to a conventional transit bus.
Plug-in electric hybridization of transit buses is being studied and experimented worldwide. One of the key challenges to managing the life-cycle costs of such buses is minimizing the number of required replacements of a reasonably sized battery during the vehicle lifetime. Battery health and usage patterns affect the number of replacements and life-cycle costs of the plug-in hybrid electric vehicle (PHEV). These are in turn governed by vehicle-related parameters such as vehicle mass, aerodynamic resistance, and rolling resistance; operating such as drivecycle, vehicle miles traveled daily, number of charges in a day, the amplitude of charging current; and battery operating conditions such as temperature of operation. Furthermore, the economic parameters such as fuel, battery, and motor prices affect the operating costs of the vehicle. Hence the effect of variation in these parameters needs to be studied to enable robust powertrain design selection. A few studies have performed the sensitivity analysis of life-cycle costs of light-duty hybrid electric vehicles (HEVs), PHEVs, and electric vehicles (EVs). Tseng et al.1 varied the annual vehicle miles for different light-duty hybrid electric technologies to conclude that higher annual vehicle miles lead to better feasibility of the hybrids. Component prices, fuel price, and vehicle miles were varied in Lin et al.2 to understand their impact on the life-cycle costs of a hybrid electric SUV. It was shown that low motor cost, high gasoline price and high vehicle miles increased the feasibility of the HEV. Battery replacement was not considered in these studies. Studies such as Shiau et al.3 have performed more detailed sensitivity analyses by varying the battery weight, distance between charges, electricity price, gasoline price, discount rate, battery cost, carbon tax, stateof-charge (SOC) swing, etc. for light-duty vehicles, while considering up to one battery replacement over the vehicle lifetime. Heavy-duty PHEVs, such as a PHEV transit bus, on the other hand, can require multiple battery replacements due to more aggressive battery usage. This further affects the life-cycle costs and the payback period (PBP). It is, therefore, necessary to understand the impact of change in vehicle operation and economic scenarios on battery utilization and costs.

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