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Optimal Selection of Equivalence Factor in Ecms For Range Extended Electric Vehicles

Keldiyarova Malika Shuhrat qizi

PhD researcher, Tashkent State Transport University, Uzbekistan

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Abstract: This study investigates the optimal selection of the equivalence factor in the Equivalent Consumption Minimization Strategy (ECMS) for range-extended electric vehicles (REEVs). The proposed approach determines the most suitable equivalence factor to ensure an effective balance between fuel consumption and battery energy usage, thereby improving energy management performance, extending vehicle range, and enhancing overall fuel economy.

Keywords: ECMS, equivalence factor, REEV, fuel economy.

INTRODUCTION

Demands for more efficient vehicles with reduced fuel consumption and low emissions are growing rapidly in these days. Generally, they can create a competition among automakers in the worldwide. In order to satisfy these factors, manufacturing of electrical vehicles (EV) can be regarded as a solution. However, short driving range and lack of charging station problems can be considered as disadvantages of the EVs. Currently, a range-extended electrical vehicle (REEV) is being developed to solve this kind of issues. A REEV's powertrain integrates two energy sources, demanding a superior energy management strategy to optimize performance and efficiency. Energy consumption minimization strategy (ECMS) is considered as the dominant strategy for splitting power between electric battery and internal combustion engine. Within ECMS, the equivalence factor translates electrical energy into an equivalent fuel consumption metric, supporting integrated energy management decisions. The selection of the equivalence factor is critical for achieving an effective balance between fuel consumption and battery energy usage.

A variety of methods for designing the equivalence factor have been proposed to improve ECMS effectiveness in the past. Gao and etc. [1] designed the equivalence factor by using weighting coefficients that are selected on the basis of the characteristics of the hybrid powertrain system and its optimal operating conditions. An adaptive equivalence factor that updates in real time was proposed by Wu et al. [2]. In the study [3], a discrete PI controller based on SOC feedback is used to update the equivalent factor in real-time. However, the method of optimal selection of fixed equivalence factor has not been discussed in the previous works. The study proposes a method to determine the optimal equivalence factor for each drive cycle

Materials and methods

The central idea of ECMS is to split power at each moment by minimizing the instantaneous equivalent fuel consumption, accomplished by translating electricity use into an equivalent fuel metric. In contrast to other EMSs, ECMS employs the equivalence factor as the control variable, defined as the ratio of energy consumed by the secondary power source to the total power requirement. The equivalent fuel consumption rate is given as Equation (1):

$$\dot{m}_{eqv} = \dot{m}_{fuel} + \dot{m}_{electr} = \dot{m}_{fuel} + s\,\frac{P_b}{LHV} \quad (1)$$

where $\dot{m}_{fuel}$ is the engine instantaneous fuel consumption; s is a pair of equivalent factors during charging (s_{chg}) and discharging (s_{dchg}); P_b is the battery power, where the value is negative when braking and the value is positive when driving; and LHV is the fuel lower heating value.

To evaluate the key ECMS parameters, a REEV model was developed in MATLAB/Simulink, utilizing the technical specifications in Table 1.

Table 1. The main specifications of REEV model

Parameter	Unit	Value
Vehicle weight	kg	1538
Electric motor		
Maximum power	kW	125
Maximum torque	Nm	250
Range extender unit		
Engine displacement	l	0.647
Engine power	kW	25
Engine torque	Nm	55
Generator power	kW	20
Battery		
Nominal cell voltage	V	3.7
Nominal system voltage	V	355.2
Rated pack capacity	Ah	60
Rated pack energy	kWh	18.8

Optimization of equivalence factor

Using a constant equivalence factor means that the conversion rate of electrical energy consumption into an equivalent fuel cost remains fixed over time. In practical implementations, the equivalence factor is often implemented as a constant due to its simplicity and ease of calibration. The selection of equivalence factor values during charging (s_chg), and discharging (s_dchg) has a significant impact on both fuel consumption and battery SOC behavior. Moreover, choosing these values appropriately ensures the optimal performance of the ECMS. This paper proposes an optimal selection method for equivalence factor values by using a correction to fuel consumption that accounts for battery SOC variation, converting it into an equivalent fuel cost [4]. The optimization of equivalence factor selection is performed by simulating the vehicle model over standard driving cycles. A range of equivalence factor values is evaluated by sweeping through them and analyzing the resulting fuel consumption and battery SOC trajectory. The optimal equivalence factor is then selected as the one that minimize the total equivalent fuel cost while maintaining the final SOC close to its initial value (i.e, $\Delta SOC = SOC_f - SOC_{initial} \approx 0$ [5]. Figure 1 illustrates how charge and discharge factors influence the variation in SOC and fuel consumption.

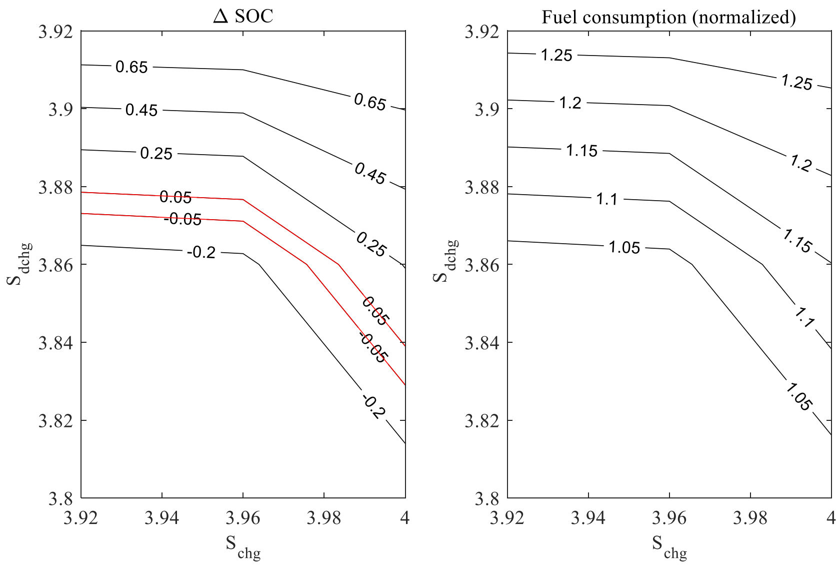

Figure 1. The changes of ΔSOC and fuel consumption (normalized relative to the lowest value) as functions of the equivalence factors s_chg and s_dchg. The simulation results obtained for the REEV vehicle model under NEDC cycle.

Based on the ΔSOC plot, charge is maintained when |ΔSOC| < 0.05 (highlighted by red line) at the end of the cycle, and this region corresponds to a fuel consumption value of approximately 1.1 in the plot. The values of s_chg and s_dchg are obtained using the bisection method within this region. This scenario is used to identify the optimal equivalence factors for various driving cycles as well. The optimal values of these factors are listed in Table 2 for different driving cycle conditions.

Table 2. Optimal values of charging and discharging equivalence factors

Drive cycle	S_{chg}	S_{dchg}
NEDC	3.96	3.875
UDDC	3.25	4.49
HWFET	3.25	4.72
WLTP	3.65	4.095

Results and discussion

In order to minimize total fuel consumption while maintaining battery SOC within allowable bounds, the powertrain model including proposed optimal value of equivalence factors was simulated under different drive cycles. The initial value of battery SOC is set to 16 %. Figure 2 demonstrates the simulation results of range extender power (P_REX) together with electric motor power (P_EM), battery power (P_batt), fuel consumption (FC), battery SOC, the value of charging (S_chg) and discharging (S_dchg) coefficients on NEDC cycle.

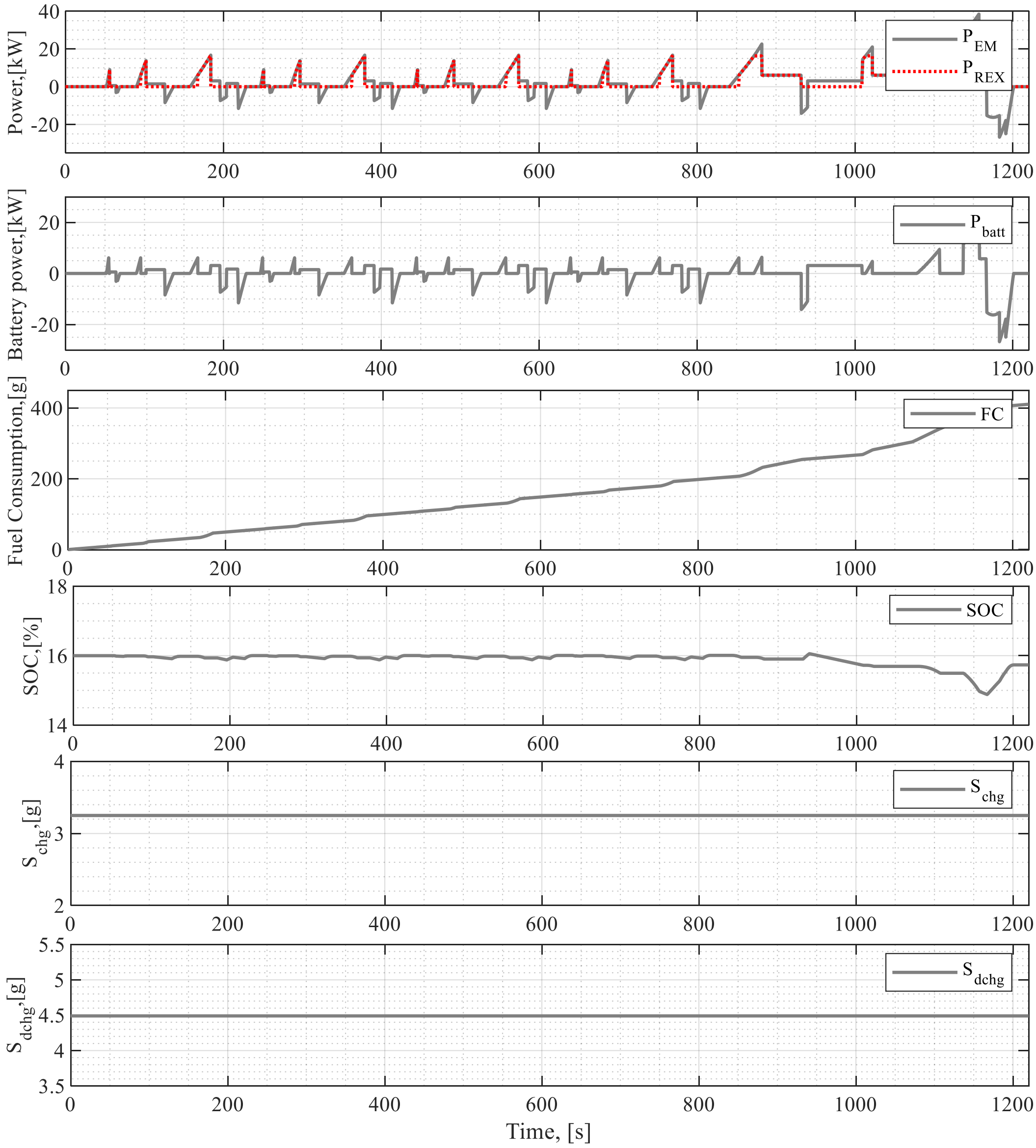

Figure 2. The simulation results for REX power together with electric motor power, battery power, fuel consumption, battery SOC, fixed charging and discharging coefficients under NEDC cycle

Conclusion

This study examines an approach to determine the optimal ECMS equivalence factors for Range extended electric vehicles. A backward-simulation REEV model, integrating the ECMS controller, was developed in MATLAB/Simulink under different driving cycles. Based on the simulation results, the battery state of charge (SOC) remains within an acceptable range.

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