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CONTEXT / MUNDARIJA

Analysis of energy management strategies for series hybrid electric vehicles

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Abstract: This paper focuses on the brief overview of available energy management strategies (EMS) for series hybrid electric vehicles. Alternatively, according to the mechanism that determines the control action, EMSs can be put into groups of rule-based and optimization-based methods. Each control method from each group has been extensively explained and compared in terms of advantages and disadvantages. The main goal of this section is to highlight important research gaps in the field as well as contribute to the increasing list of review debates.

Keywords: Rule-based method, thermostat, equivalent fuel consumption minimization strategy, series hybrid vehicle

1. Introduction

The number of electrified vehicles is increasing significantly due to reduce the consequences of exhaust gases from conventional vehicles in these days. Several architectures of electrified vehicles are available according to the number and location of energy sources. Pure electrical vehicles have only a large battery and it is a source for the propulsion. These kinds of vehicles do not exhaust any harmful emissions but they have limited driving range for long trips. In order to extend driving range of pure electrical vehicles, internal combustion engine is used as a second energy source. The vehicles which have more than a power source are called hybrid electric vehicles (HEV). Based on the location of energy sources, there are three types of HEVs. Series HEV, parallel HEV and series-parallel HEVs are commonly used to design vehicles in industry. HEVs require a supervisory algorithm which controls drivetrain components. The most point of control problem in HEVs is an instantaneous management of the power flow from the battery and the second power source in order to reach minimum fuel consumption with low emissions and to decrease the system cost while achieving good driving performance. In the series hybrid powertrin structure, the internal combustion engine (ICE) is disconnected to the wheels which engine operates at the highest efficiency point and it can be enable to control powertrain easier than other structure of HEVs [1]. Two common control strategies are to be discussed and analyzed for series HEVs including thermostat and energy consumption minimization strategy (ECMS).

2. Materials and methods

Several methods are developed to manage required power between two energy sources. The rule based and global optimized energy management strategies are commonly used to design vehicles. Thermostat control strategy is a type of rule based and it is not optimized yet. Whereas, ECMS is a type of optimized control method.

In order to analyze thermostat and ECMS for series hybrid system, data of the BMW i3 REX vehicle was used to validate the results. The main specifications of the vehicle is shown Table 1 [2].

Table 1

Mass	1315	kg
Engine power	25	kW
Electric motor power	125	kW
Battery capacity	60	Ah
Battery power	18.2	kWh

3. Series hybrid electric vehicle system

In series hybrid electric vehicle architecture, an electric motor delivers all required power to the wheels from electric battery and the generator which is connected to the ICE. The supervisory controller determines at each time how to split requested power (P_r) between generator powered by ICE and battery. Figure 1 describes how to split requested power among components of series HEV.

$$P_r = P_{gen} + P_b \quad (1)$$

According to the state of charge (SOC) of battery and required mechanical power, the generator helps to power the electric motors or helps to charge the battery. Due to the mechanical decoupling of the ICE from the wheels, it is realizable to operate ICE with higher efficiency [3].

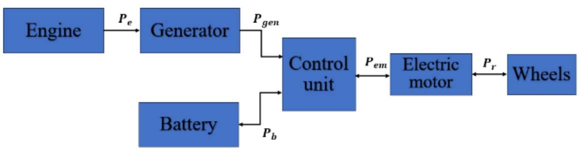

Figure 1. Series HEV structure

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4. Thermostat control strategy

The energy management of series hybrid structure is more sample than parallel and series-parallel structures of HEVs. The thermostat control strategy is based on some logical rules and it is most common method to control engine. In this method, the engine is controlled by SOC of battery. When the SOC of battery reaches to its lower point, the engine will turn on and operates with constant value at high efficiency point. Whereas, when the SOC reaches to its higher point, the engine will turn off and drivetrain is completely propelled by battery. Therefore, the engine operates ON or OFF mode then, equation (1) is rewriten as a following equation [4].

$$P_g = \begin{cases} 0, & SOC > SOC_h, \quad OFF \\ P_r - P_b, & SOC_L < SOC < SOC_H, \quad ON \end{cases}$$

Where, P_g is engine connected generator power and P_b is battery power.

5. Energy consumption minimization strategies

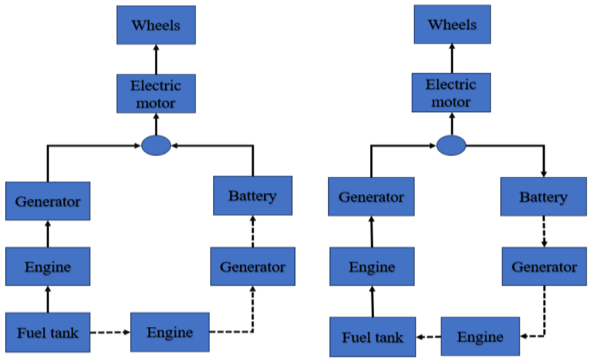
Thermostat control strategy is sample and robust, therefore it does not required supervisory controller for series HEV system. On the other hand, it is not optimized to reach minimum fuel consumption and other performances. In these years, scientists focus on optimizing the power split by minimizing instantaneous fuel consumption for HEVs.

The main concept of ECMS is to minimize fuel consumption at each time instant by converting electricity consumption into the equivalent fuel consumption. The dimensionless conversion ratio is called equivalence factor and it is control variable of ECMS. The equivalent fuel consumption rate is given as equation (4).

$$\dot{m}_{fc} = \dot{m}_f + \dot{m}_e = \dot{m}_f + \frac{s}{Q_{LHV}} P_e \qquad (4)$$

Where, $\dot{m}_f$ – intantaneous fuel consumption of the engine, s – equivalence factor, Q_{LHV} – lower heating value of fuel and P_e – electric motor power.

At any moment, the electric energy discharged from the battery needs to be recharged back to the battery in the future. This is equivalent to positive fuel consumption of the engine. On the other hand, the energy charged to the battery at any moment will also be discharged from the battery to drive the vehicle in the future. This is equivalent to negative fuel consumption for the engine [5]. The basic principle of ECMS for series HEV is shown on Figure 2.



a) negative fuel consumption b) positive fuel consumption

Figure 2. The basic principle of ECMS for series HEV

6. Results and discussion

Based on the architecture and design parameters, a series HEV model was built in MATLAB/Simulink software [6]. Thermostat control strategy was simulated and evaluated using this model.

The results were compared with experimental data which was collected on Argonne National laboratory [7]. It is shown that, working line of the ICE is the same with experimental data. However, there were some disrepancies on fuel consumption because the thermostat control strategy is not optimized. Figure 3 shows the comparison of ICE speed and fuel consumption with experimental data.

7. Conclusion and future work

Thermostat and energy consumption control strategies for series HEV have been analyzed in this paper. Validation of the thermostat control strategy has been done on the designed model of seies HEV using data of BMW i3 REX. The engine speed and fuel consumption have been compared and with experimental data In the future studies, optimized method which is ECMS will be designed for this model to improve fuel consumption and other performances.

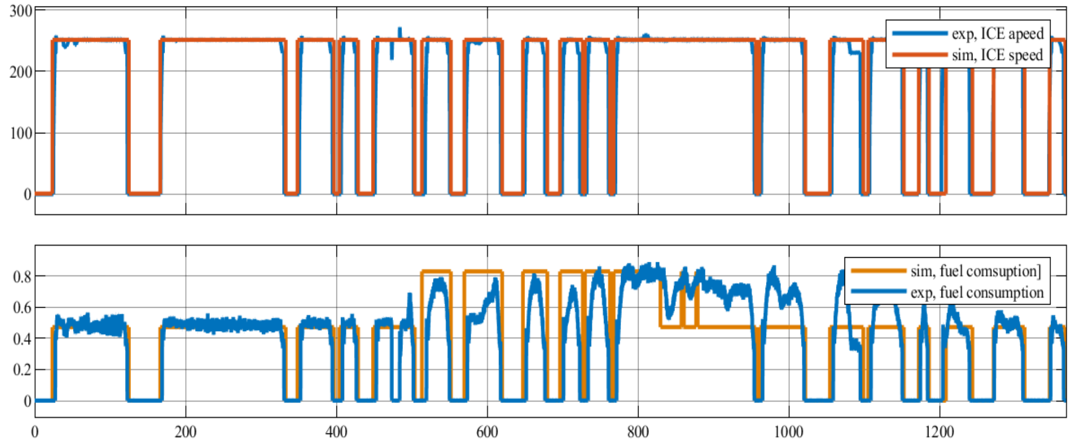


Figure 3. Comparison of ICE speed and fuel consumption of series HEV

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