EVS30 Symposium
Stuttgart, Germany, October 9 - 11, 2017

Power Distribution Optimization in Series Hybrid Electric Bus Using Ultracapacitor

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Summary

We adopted an Ultracapacitor (UC) for improving the fuel efficiency of a series hybrid electric bus. By utilizing the driving characteristics of the series hybrid electric bus with UC, we were able to achieve better fuel efficiency than the series hybrid electric bus without UC. In this paper, we introduce the model which added the UC to the existing hybrid vehicle. Further, the operation of UC is determined by the running speed of the vehicle.

Keywords: Powertrain, Energy storage, HEV(Hybrid Electric Vehicle), bus

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1 Introduction

Conventional automobiles have a great impact on the environment and the problem of exhaust gas generated by existing internal combustion engine vehicles is worldwide interests. To overcome this problem, interest in hybrid vehicles, which are realistic eco-friendly vehicles, become widespread. Conventional hybrid automobiles have been developed to support the energy demanded using motors, batteries, and internal combustion engines. However, this study is based on a series hybrid automobile which adopt additional Ultracapacitor (UC) [1]. The vehicle models using battery only and UC together were calculated, such that the effect of increasing fuel efficiency was verified when adding an UC. The following chapter 2 introduces the type of powertrain presented in the paper [6], chapter 3 describes the characteristics and SOC of the Hybrid Energy Storage System (HESS) [4][5], chapter 4 introduces the fuel efficiency factor, and chapter 5 introduces the control strategies[3]. Finally, chapter 6 introduces the interpretation of simulation results, and chapter 7 introduces future research plans.

2 Powertrain

The powertrain presented in this paper is equipped with an additional UC in parallel in addition to a series hybrid system with a battery. The reason for connecting the battery and the UC in parallel is to operate the UC like a battery such that fully facilitate the Energy Storage System (ESS) is possible. The UC and the battery are connected in parallelwhere the UC also plays the role of the battery. The addition of an UC has increased the weight of the vehicle. Table 1 shows the brief vehicle specifications of the system.

Table 1: Basic parameters of the vehicle

Weight (Ton)	Motor (kW)	Wheel Rim Diameter (m)	Air Drag Coefficient	Front Area (m^2)	Voltage (V)
16	100*2	0.5715	0.6	6.6	540

3 Hybrid Energy Storage Systems

ESSs are a very important role in electric, hybrid and plug-in hybrid vehicles and batteries are among the most widely used of various energy storage systems. For battery ESS, the power density of the battery should be high enough to meet the maximum power. Batteries with higher power densities can be used to meet this, but they have the disadvantage that they are very expensive. In order to solve this problem, there is a method of increasing the size of the battery, but this is also disadvantageous because of the cost. So, we propose HESS to solve the above problem. The HESS presented in this paper improves performance by combing battery and UC [8].

3.1 Characteristic of HESS

The battery used as the energy storage device reacts electrochemically, while the UC has the electrostatic characteristics. Unlike batteries that use chemical reactions, UC use simple ion transfer and electrochemical recharge from electrodes and electrolytes. As a result, it can be rapidly charged and discharged, has high charging/discharging efficiency, and has a semi-permanent lifetime characteristic, and is being watched as a next generation energy storage device. The frequent starting and stopping characteristics of the bus driving cycle were used to control the operation timing of the UC.

3.2 State of Charge Range in UC

Due to the characteristics of the UC described above, the UC does not become a problem in its lifetime even when overcharging of overdischarging is performed. The UC voltage and SOC state are given by:

$$dV^{+} = \frac{V^{+}{}_{steady} - V^{+}}{\tau} \tag{1}$$

$$V^{+}{}_{steady} = \frac{Q}{C} + RI^{+} + V^{-} \tag{2}$$

where $V^{+}{}_{steady}$ is steady-state output voltage[V], Q is the charge of the capacitor[C], C is the capacitance[F], R is the equivalent internal resistance[Ohm], I^{+} is the input current[A], τ is the voltage time constant[s], V^{-} is the potential voltage[V]. The capacitor output voltage derivative dV^{+} is calculated.

The charge used by the load Q[C] is calculated as follows:

$$\frac{dQ}{dt} = -I^{+} \tag{3}$$

the capacitor discharges when the capacitor terminal current I^{+} is negative.

3.3 State of Charge Range in Battery

As with UC, battery must also maintain adequate SOC conditionsbecause of the charging and discharging efficiency of the battery. However, it should be noted that the charge/discharge efficiency varies from battery to battery. In this paper, verification is performed based on Thermostat Control Strategy (TCS) which is the most common control strategy. The TCS limits the SOC state to 40 to 60% and is used within this range. The principle of operation is simply to start charging through the engine / generator when the SOC of the battery reaches 40%, stopping the engine / generator when it reaches 60%, and continue using the battery [1].

4 Fuel efficiency factor

The drive cycle of the bus is characterized by frequent start and stop. Especially, the energy consumption is the most when the vehicle starts. Therefore, if the UC is used in a low acceleration region where the vehicle starts, it is possible to reduce the area where the battery has been burdened. This has the advantage of reducing battery usage and extending battery life. As a result, the reason for setting the acceleration of the vehicle as the second design variable of the optimization is as follows. This is due to the running resistance of the vehicle. The running resistance of the vehicle consists of air resistance, rolling resistance, gradient resistance, acceleration resistance, and traction resistance [1]. In this paper, we have performed flat running and acceleration resistance and traction resistance are neglected because they do not affect the overall running resistance. Therefore, the final running resistance consisted of rolling resistance and air resistance. This can be expressed as the following equation[1].

$$F_w = F_a + F_R = \frac{1}{2}\rho A C_D (V - V_w)^2 + f_R \bullet m \bullet g \tag{4}$$

where F_w is the total running resistance, F_a is the air resistance, F_R is the rolling resistance, ρ is the air density $[kg/m^3]$, A is the vehicle front area $[m^2]$, C_D is the drag coefficient, V is the vehicle speed $[m/s]$, V_w is the wind speed $[m/s]$, f_R is the rolling resistance coefficient.

5 Control Strategy of the Engine and HESS

The drive train presented in this paper is a series hybrid drive train. Its operating principle is to drive the motor through the HESS and the engine/generator to charge the HESS. When charging the HESS, the engine/generator minimizes fuel consumption by operating in the area with the highest efficiency [1][7]. The operation of the engine/generator depends on the SOC of the battery and UC. In this paper, we have chosen TCS, which are widely used as the common control strategy.

5.1 Control Mode

Based on the characteristics of the ESS introduced above and the universal control strategies, we introduce the operation mode for efficiently operating the HESS. Through efficient energy distribution, we intend to maximize the effect of fuel economy factor proposed in this paper. There are two kind of operation modes to be presented, and they are classified according to the state of SOC of the battery.

5.1.1 Mode 1

In mode 1, the SOC state of the battery is 40% or less. The figure 1 is an energy flow chart [3][8]. In mode 1, the initial operation of the vehicle is performed with an UC, and the vehicle is operated while charging the battery through the engine/generator. Instead of using an UC, in an area where the battery is used, the UC is charged through the engine/generator. When the UC is fully charged, the forced operation of the battery stops and continues to run while charging the battery.

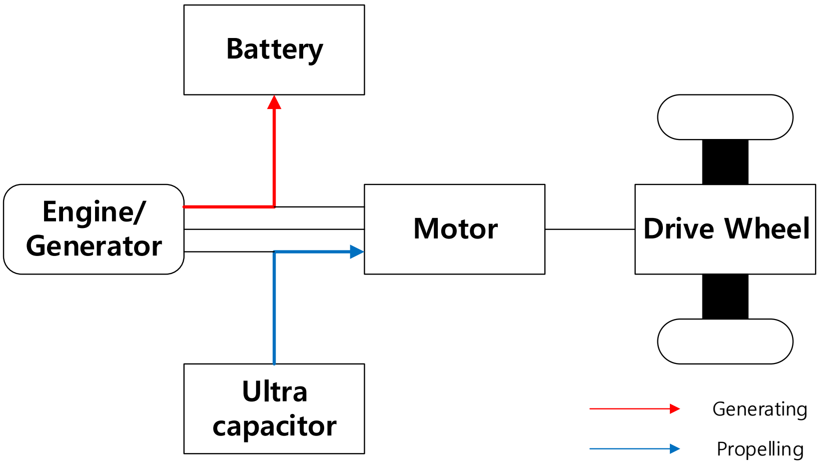

Figure 1: Mode 1 energy flow

5.1.2 Mode 2

In mode 2, the SOC of the battery is sufficient. The figure 2 is an energy flow chart in mode2[3][8]. In this case, the vehicle drives the vehicle with an UC at the starting point, and drives the vehicle using the battery at a further point in time. If the SOC of the UC becomes low, a battery with sufficient SOC status will be used unlike Mode 1. In the above case, which is relatively more efficient than Mode 1 is used. It also charged through the engine/generator when the SOC state of each energy storage device reaches the lower limit.

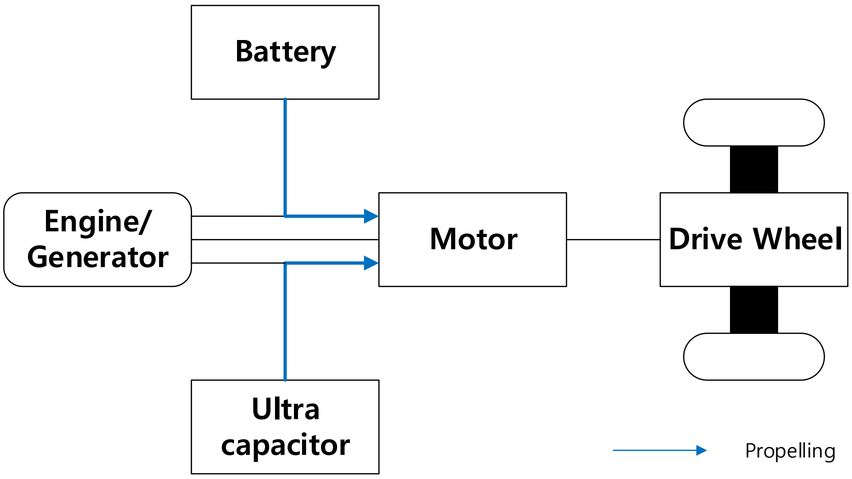

Figure 2: Mode 2 energy flow

6 Simulation Result

The simulation was performed by co-simulation of Matlab/Simulink and Amesim software. From the simulation results, the drive cycles used in the simulation were two cycles, which was Manhattan cycle and Braunschweig cycle. In order to perform the optimization, the timing of using the UC is set as the acceleration of the vehicle. As a result, the fuel efficiency showed a tendency to increase.

7 Conclusion

This paper introduces a model with an additional energy storage device called UC in order to further improve the fuel efficiency of hybrid buses using existing batteries. In the proposed model, the using timing of the UC, which is the fuel efficiency increasing factors, is set as the design variables. This is applied to TCS, which is the most commonly used control strategy. Future research will reduce the weight of the vehicle through capacity matching of HESS and expect fuel efficiency to rise.

Acknowledgments

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (2016R1D1A1B03936328).

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