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Optimal Control Strategy According to the Workload of a Fuel Cell-Battery Hybrid Excavator

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Summary

Affordability of the total required power due to the workload is the most important for the fuel cell and a battery in the hybrid power train. Optimal control strategy shall consider the required power first which needs to be satisfied with the power train and the state of charge (SOC) of the battery, hydrogen usage as second. Accordingly, in this paper, we propose to the optimal strategy of power distribution according to the operation load of the fuel cell hybrid excavator.

Keywords: Fuel cell, Battery SOC, Optimal control, Power distribution, Fuel consumption

1 Introduction

Researches of the power distributed by the combination of mechanical energy was the main issue of the power train of the conventional hybrid vehicle. The power distribution between an engine and motors was determined by utilizing the optimal control such as Dynamic Programming, Pontryagin's Minimum Principle or rule-based control.[1] However, the combination of electrical energy in the hybrid power train including fuel cell is a major research issue currently because the traction motors are supported by fuel cell and a battery. There are a lot of cases of the use of the fuel cell hybrid powertrain recently among the construction machinery. The power train of hybrid excavators including fuel cell, auxiliary supported by a battery bears most of the load according to the work in the construction field. Depending on the support of the battery excavators are more able to afford a big workload, but need to consider the battery state of charge (SOC) and hydrogen usage through effective operational strategies. If the battery SOC is lower than a threshold, the charging by the fuel cell or the regenerative braking is activated to increase the SOC for sustenance. When the opposite case, the discharge of the battery is activated. Quantity of hydrogen usage is minimized in both cases. [2]

2 System Configuration

The hydraulic motor of the hybrid excavator is driven by the fuel cell and the battery. That is, the electric energy generated by the fuel cell and the battery is transmitted to the hydraulic motor through the DC / DC converter and the inverter. It is converted into kinetic energy by an AC motor and finally converted to hydraulic energy from a hydraulic motor. The theoretical values were applied to the battery and fuel cell models of the simulation.

2.1 Battery Model

Internal resistance model of a lithium-ion battery applied to an actual hybrid excavator was applied to the simulation. Internal resistance, voltage, and current according to battery SOC were used. [3]

$$\dot{SOC} = \frac{V(SOC) - \sqrt{V(SOC)^2 - 4 \cdot R(SOC) \cdot P_{bat}}}{2 \cdot R(SOC) \cdot Q_{bat}} \quad (1)$$

2.2 Fuel Cell Model

The hydrogen consumption applied to a hybrid excavator is determined by voltage and power of the fuel cell. The formula is as shown below. F is Faraday constant. [4]

$$C_{H_2} = P_e / 2 / V_c / F \quad (2)$$

3 Dynamic Programming

Dynamic programming applied to the hybrid excavator in this study consists of N stages of time step, conditional parameter x in k stage of N, and control parameter u. Optimization is defined as shown below.

$$x(k+1) = f(x(k), u(k)) \quad (3)$$

$J_{k,N}(x(k))$ is the optimal route from k stage to final stage. The dynamic equation as shown below. [5]

$$J_{k,N}(x(k)) = \min\{L(x(k), u(k)) + J_{k,N+1}(x(k+1))\} \quad (4)$$

Above equation expresses dynamic programming which is solved by backward way. If the optimal route form k+1 stage to final stage is known, the optimal route from k stage to final stage can be calculated. from the dynamic equation. Cost function J is the function of hydrogen consumption and battery SOC change in the view of the power distribution problem of the hybrid excavator. Control parameter u is the battery power in each time step. [6]

4 Simulation Results

The results of the simulation of the distribution of the working power of the engine excavator into the power of the fuel cell and the battery are as follows. The SOC change and the power distribution result can be different based on the SOC to be maintained and the initial SOC. The powertrain of the construction machine represented by the excavator is applied the theoretical study about the power distribution like the hybrid vehicle.

4.1 Battery Charge

When the SOC of the battery changes from 0.69 to 0.7, the power distribution simulation between the fuel cell and the battery is performed. Most of the demand power is satisfied by the fuel cell, and the charging of the battery is also achieved by the fuel cell. After reaching the target SOC, the fuel cell and the battery cover the demand power.

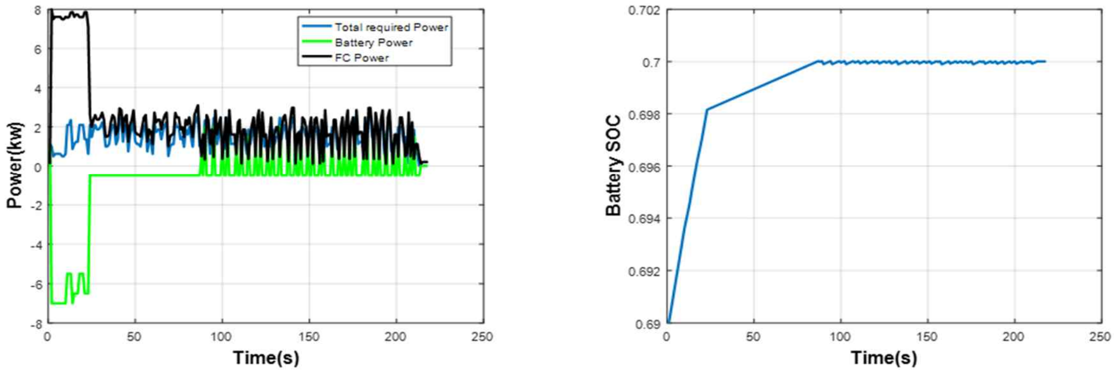

Figure 1: Power Distribution Results of the Simulation (Battery Charge)

4.2 Battery Discharge

When the SOC of the battery changes from 0.71 to 0.7, most demand power is covered by the battery. After reaching the target SOC, the fuel cell and the battery cover the demand power.

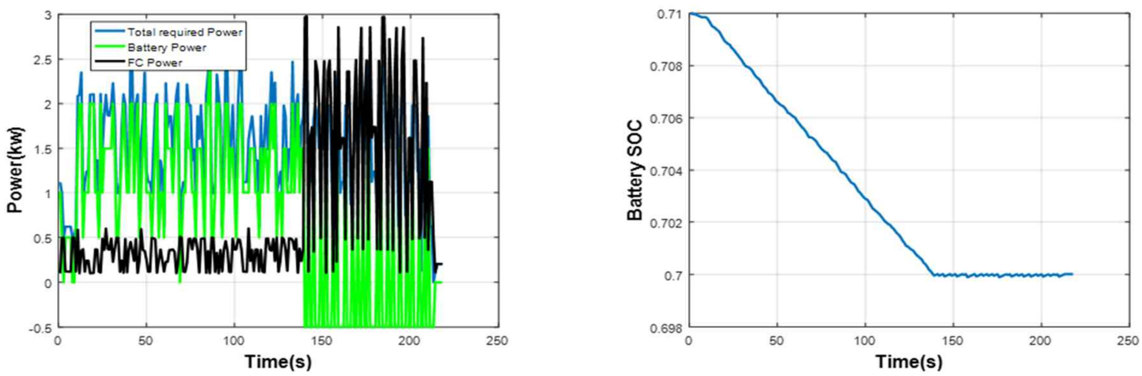

Figure 2 : Power Distribution Results of the Simulation (Battery Discharge)

4.3 Battery SOC Sustaining

When the SOC of the battery is maintained at 0.7, the fuel cell and the battery cover the demand power. The fuel cell plays a larger part than the battery to maintain the SOC of the battery.

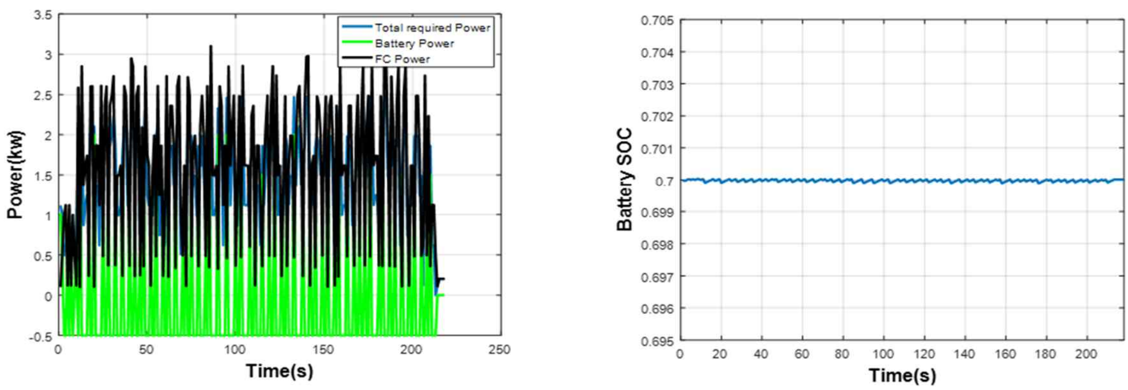

Figure 3 : Power Distribution Results of the Simulation (Battery SOC sustaining)

5 Conclusion

Simulation of power distribution between fuel cell and battery according to change of battery SOC was performed. It is confirmed that the power distribution result is changed according to the change of the battery SOC even in the same demand power, and it is understood that the setting of the initial SOC is important. These simulations are expected to be of great help in the development of real electric excavators in the future and will be used for capacity selection of fuel cell and battery. As with hybrid vehicles, various types of electric excavators can be used depending on the capacity of the power source, and capacity selection according to the above simulation makes it possible to select suitable types of electric excavators.

Acknowledgments

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References

[1] James Larminie et. Al., *Fuel Cell Systems Explained,* ISBN 0-470-84587-X, Chichester, John Wiley & Sons Ltd., 2003

[2] Hofman T., Steinbuch M. et. Al., *Rule-Based Energy Management Strategies for Hybrid Vehicles,* International Journal of Electric and Hybrid Vehicles, ISSN 1751-4088, 1(2007), 71-94

[3] Kessels J., Koot M. et. Al., *Online Energy Management for Hybrid Electric Vehicles,* IEEE Transactions on Vehicular Technology, ISSN 0018-9545, 57(2008), 3428-3440

[4] Zheng C., Cha S. et. Al., *PMP-Based Power Management Strategy of Fuel Cell Hybrid Vehicles Considering Multi-Objective Optimization,* International Journal of Precision Engineering and Manufacturing, ISSN 2234-7593, 57(2013), 3428-3440

[5] Elham Hosseinzadeh et. Al., *Performance Simulation and analysis of a fuel cell/battery hybrid forklift truck,* International Journal of Hydrogen Energy, ISSN 0360-3199, 38(2013), 4241-4249

[6] Hyun-Sub Lee et. Al., *Rule-Based Power Distribution in the Power Train of a Parallel Hybrid Tractor for Fuel Savings,* International Journal of Precision Engineering and Manufacturing-Green Technology, ISSN 2288-6206, 3(2016), 231-237

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