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Effects of Battery Thermal Management System in HEV/EV to Temperature and SOC Based on Simulation

Jongwoo Choi[1], Gu Young Cho[1], Joonho Park[1], Suk-Won Cha[1]
[1] School of Mechanical and Aerospace Engineering, Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul 151-744, Korea, swcha@snu.ac.kr

Abstract

Effects of thermal management system for battery pack are simulated in this paper. With increasing demands for HEV/EV, management system for battery pack is now one of the most interesting topics in this field. Maintaining temperature and SOC of battery packs to their optimum condition affects a lot to the battery performance. If the temperature of battery pack is too low, it cannot supply enough electric power to the vehicle. On the contrary, if the temperature is too high, safety problem exists. Same thing happens when the SOC of battery pack changes. To avoid these problems, battery management system (BMS) is needed. Among many functions of the battery management system, battery thermal management is simulated. Battery thermal management system helps to keep optimum temperature of battery pack using heating and cooling system. However, during heating and cooling process, SOC of battery decreases. Thus, battery thermal management itself has both positive and negative effect to the battery pack. Simple air cooling type thermal management system is assumed for simulation. Experimental data are used for OCV and charging/discharging resistance. Fan control signal is classified as 8 stages according to the pack temperature. As fan speed becomes faster, decreasing rate of both SOC and temperature becomes faster.

Keywords: BMS, battery management, thermal management, lithium battery

1 Introduction

Along with increasing interests to environment and energy, Electric Vehicle (EV) is now one of the most promising technologies in the field of vehicle research. Using battery as their main power source, EVs are free from high oil price and environmental issues compared to the vehicle using combustion engine as main power source.

Despite the advantages of EV, EV has not been commercially popular. Basic technologies for EV are now under developed and would take more time to be completed. Hybrid Electric Vehicle (HEV) is kind of a transitional technology to solve problems of EV and to obtain advantages of both engine vehicle and electric vehicle.

This paper presents temperature issue of battery in EV/HEV. Temperature of battery is mostly affected from heat generation of battery pack. During driving, charging and discharging processes are repeated. Input and output current of battery would suffer from internal resistance. Therefore, heat generates and temperature of battery increases

Temperature issue of battery become one of the major issues in EV/HEV development these days. Too low or too high temperature would make battery life decreasing, or even become the reason of explosion. Beside of the life issue, battery temperature affects internal resistance, discharging power, and so on. [1][2] Battery Thermal Management System (TMS) is needed to control battery temperature so that battery can work under best temperature condition.

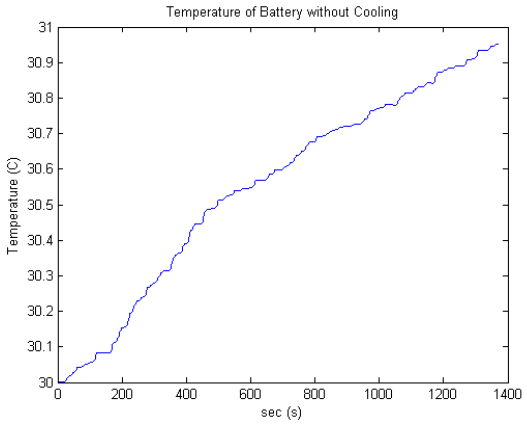

Figure1: Increasing of Battery Temperature during Driving

Simple fan-type air cooling system is assumed for Battery TMS. Though liquid-type cooling system works better for decreasing temperature, fan-type air cooling system needs lower energy than liquid-type. Furthermore, air-type cooling system has no need to consider coolant leaking, which can be very dangerous situation for battery. In this paper, effects of Battery TMS to temperature and SOC are introduced. TMS operation consumes SOC but decreases temperature. And decreasing temperature affects internal resistance, which affects SOC again. By optimizing TMS logic, it is possible to obtain best temperature and SOC conditions.

2 Modeling

2.1 Simulation Program

Two programs are used during simulation. MATLAB Simulink® is used for making and modifying simulation model. Autonomie® of Argonne National Laboratory is used for running simulation.

Autonomie® provides basic car models and components models. In case of battery, 5 models exist. 'Generic map' model is used for simulation. This model contains open circuit voltage and internal resistance map to calculate voltage drop and heat generation. By changing maps in the model to the experimental values, it is easy to make appropriate battery model.

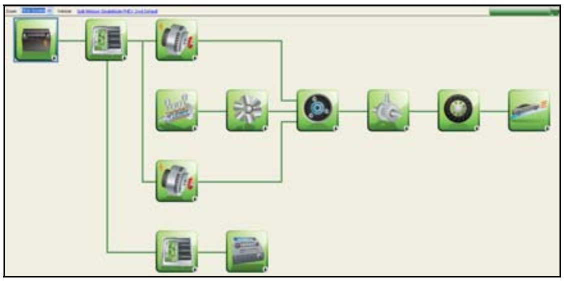

Figure2: Initial Car Model in Autonomie®

2.2 Simulation Model

Figure3: Battery Thermal Management System Model

Simulation model is presented above. Model consists of four modules. Each module calculates current, SOC, voltage and temperature.

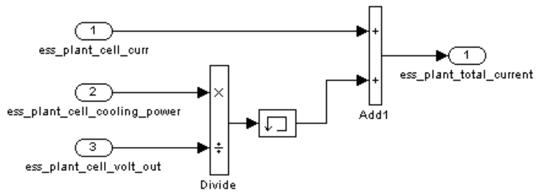

Figure4: Current Module

Current module simply calculates current of battery by adding currents for each component. Currents for motors, electric components and thermal management system are added in this module.

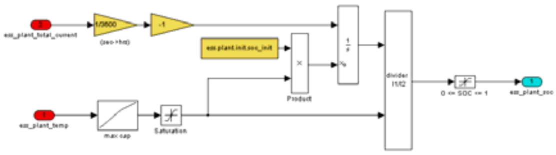

Figure5: SOC Module

SOC module also simply calculates SOC using current for charging/discharging process.

Voltage module calculates voltage of battery pack using open circuit voltage and internal resistance. Open circuit voltage and charging/discharging resistance are imported to the module as a form of map. Maps are arranged by temperature and SOC. Open circuit voltage and internal resistance are exported from maps by temperature and SOC at each time.

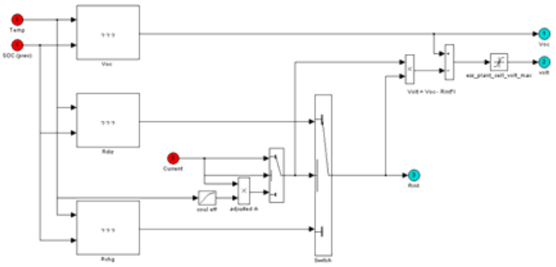

Figure6: Voltage Module

SOC and voltage modules are same as modules in the initial ‘generic map’ model. Temperature module is totally new one. Current module is modified to add current for temperature module.

There are three submodules in the temperature module. Thermal management submodule decides flow rate and thermal resistance. Heat generation submodule calculates battery heat generation. Battery temperature submodule calculates heat transfer and final battery temperature.

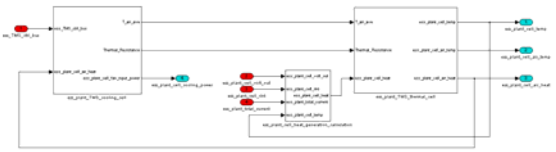

Figure7: Temperature Module

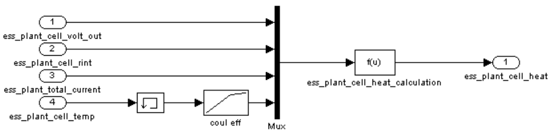

Figure8: Heat Generation Submodule

Heat generation submodule calculates battery heat generation. Basic theory of calculating heat generation is simple voltage loss due to internal resistance. During charging process, current loss due to charging is also considered. This term is added by coulombic efficiency.

$$Q_{gen,dis} = I^2 R \tag{1}$$

$$Q_{gen,chg} = I^2 R + (1-\eta_{coulombic}) IV \tag{2}$$

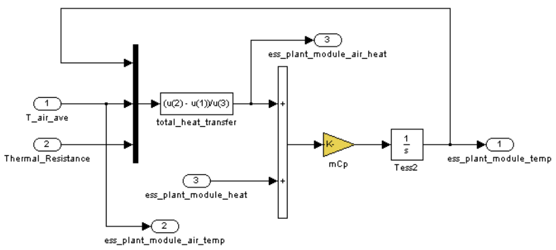

Figure9: Battery Temperature Submodule

Result of heat generation submodule is delivered to the battery temperature submodule. Battery temperature submodule uses generated heat and transferred heat to calculate battery temperature change. Battery pack mass and specific heat data are needed to calculate temperature change.

$$T = T_{init} + \int \frac{Q_{gen} + Q_{trans}}{MC_p} dt \tag{3}$$

Heat transfer between battery pack and cooling air is calculated using thermal resistance.

$$Q_{trans} = \frac{T_{air} - T_{battery}}{R_{thermal}} \tag{4}$$

Thermal resistance is calculated at the thermal management submodule. Convection heat transfer and conduction heat transfer are considered. Nusselt number based on the air velocity is needed to calculate convection heat transfer coefficient.

Convection heat transfer coefficient is needed to be calculated from basic heat transfer equations. Nusselt number based on the air velocity is used.

$$Nu_D = \frac{hD}{k} = 0.023 \mathrm{Re}_D^{4/5} \mathrm{Pr}^{1/3} = 0.023 \left(\frac{\mathrm{v}D}{\nu} \right)^{4/5} \mathrm{Pr}^{1/3} \tag{5}$$

Using Nusselt number equation, convection heat transfer coefficient can be calculated. Thermal resistance can be calculated from heat transfer coefficients and heat transfer areas. [3]

$$R_{thermal} = \frac{1}{hA_{conv}} + \frac{\delta}{kA_{cond}} \tag{6}$$

Convection heat transfer coefficient has different values based on the velocity. Therefore, to calculate thermal resistance, cooling air velocity has to be decided.

High cooling fan speed provides high air velocity and high heat transfer coefficient, which means high heat transfer rate. At the same time, high cooling fan speed needs high SOC usage. Thus, to decrease temperature changing rate faster than before, more battery power is needed.

To use battery thermal management system efficiently, control logic is important. By deciding fan speed at each temperature, it is possible to optimizing SOC usage and temperature maintenance. In this paper, 8 stage fan control signal is assumed to control fan speed. Fan does not work or works from its minimum speed to maximum speed at each stage.

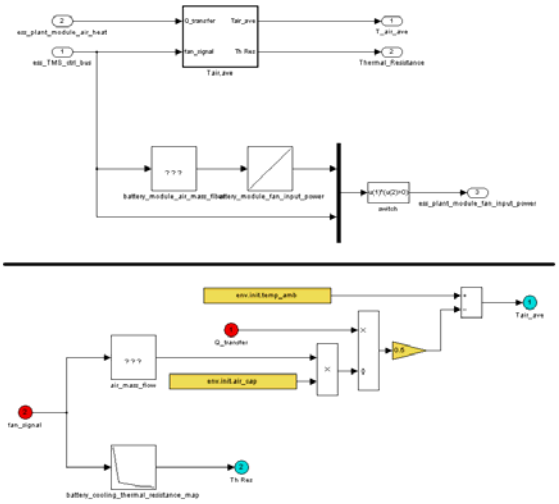

Figure10: Thermal Management Submodule

Thermal management submodule decides air flow rate from delivered control signal. Then it calculates thermal resistance, air temperature change and fan power.

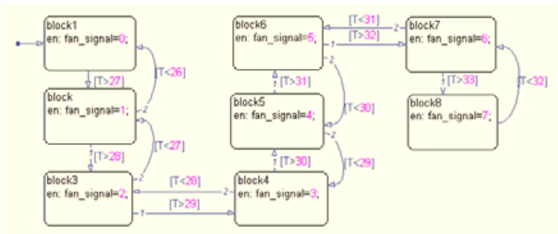

Figure11: Fan Control Signal Flow Chart

3 Simulation

3.1 Process

Battery pack level simulation is done. Fixed current discharging driving condition is assumed to identify temperature change due to working battery only. Thermal equilibrium is assumed between battery pack and ambient air at the initial stage. Battery temperature, SOC, fan control signal and fan power data are exported.

3.2 Result

Temperature and SOC results are shown in figure 12 and 13.

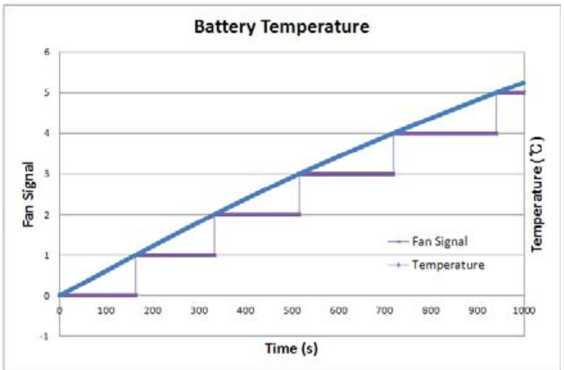

Figure12: Pack Level Simulation Result: Temperature

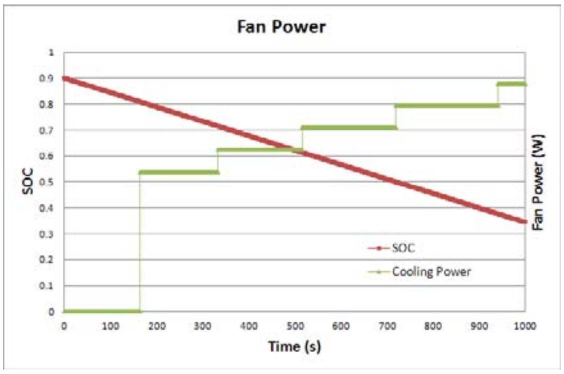

Figure13: Pack Level Simulation Result: Fan Power

During discharging, SOC of battery pack decrease. Since fixed current discharging is assumed, SOC graph is nearly a straight line.

Temperature of battery pack increases due to internal resistance. At the first time, temperature is low so that there is no need to make fan to work. As time goes on, temperature of battery pack increases and cooling is needed. After some pre-fixed temperature, fan starts to work. Fan speed becomes faster as temperature of battery pack increases. Faster air speed produces more heat transfer from battery pack to the air. It helps to make temperature increasing rate lower.

However, at the same time, faster fan speed needs more power. To make temperature increasing rate lower, more power is needed. It directly affects SOC of the battery pack.

4 Conclusion

Simulation about battery thermal management system is done in this paper. Simple air cooling type system is assumed to make simulation model. 8-stage control signal for the fan is used to control fan speed. Objective of this paper is to know how battery thermal management system in HEV/EV affects temperature and SOC.

1. During driving, charging and discharging process occurred. Due to internal resistance, heat generates inside of the battery pack. Therefore, temperature of the battery pack in HEV/EV increases during driving.
2. Battery thermal management system helps to decrease temperature increasing rate of battery pack. However, since electric components consist thermal management system, it has disadvantage in the SOC side.
3. To maintain optimum temperature and optimum SOC, developing control logic of thermal management system is important.

Acknowledgments

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Authors

Graduate student, Jongwoo Choi
School of mechanical and aerospace engineering
Seoul National University
San 56-1 Daehak-dong Gwanak-gu, Seoul, 151-742, Republic of Korea
Tel: +82-2-880-8050
E-mail: snio89@snu.ac.kr

Jongwoo Choi is currently a MS student in college of engineering of Seoul National University. His working field is modelling of lithium ion battery and TMS of battery pack.

Graduate student, Gu Young Cho
School of mechanical and aerospace engineering
Seoul National University
San 56-1 Daehak-dong Gwanak-gu, Seoul, 151-742, Republic of Korea
Tel: +82-2-880-8050
E-mail: sepril02@snu.ac.kr

Gu Young Cho is currently a PhD student in college of engineering of Seoul National University. His working field is simulation of lithium ion battery, TMS of battery pack and experiments of SOFCs.

Graduate student, Joonho Park
School of mechanical and aerospace engineering
Seoul National University
San 56-1 Daehak-dong Gwanak-gu, Seoul, 151-742, Republic of Korea
Tel: +82-2-880-8050
E-mail: pjh1304@snu.ac.kr

Joonho Park is currently a PhD student in college of engineering of Seoul National University. His working field is simulation of TMS of battery pack and SOFCs.

Graduate student, Suk Won Cha
School of mechanical and aerospace engineering
Seoul National University
San 56-1 Daehak-dong Gwanak-gu, Seoul, 151-742, Republic of Korea
Tel: +82-2-880-1700
E-mail: swcha@snu.ac.kr

Suk won Cha received MS and PhD in Department of Mechanical Engineering from Stanford University, in 1999 and 2004 respectively. From 2003 to 2005, he was a Research Associate in Department of Mechanical Engineering, Stanford University. He is currently an Assistant Professor in School of Mechanical and Aerospace Engineering, Seoul National University. His research interests are fuel cell systems, design of hybrid vehicle systems and application of nanotechnology to SOFCs.