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A Study on Thermal Management System of Lithium ion Battery for HEVs and EVs

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Abstract

Lithium ion battery is the most promising energy storage system for Hybrid Electric Vehicles (HEVs) or Electric Vehicles (EVs) because of its high open circuit potential, high energy density, low self-discharge. However, safety problems like thermal runaway and performance degradation problems in very high / low temperature are most critical issues for lithium ion batteries. Therefore most lithium ion battery pack for HEVs of EVs has thermal management system to maintain the temperature of the battery pack in optimal range. In this study we make a model of the lithium ion battery pack with air cooled thermal management system. In lithium ion battery model and heat generation model, we consider electrochemical reactions for negative and positive electrodes by Butler-Volmer equations. And we make the strategy for air cooling thermal management system. Then, Simulation results are matched very well with experimental results.

Keywords: battery management, cooling, Lithium battery, Hybrid Electric Vehicle (HEV), Electric Vehicle (EV), simulation

1 Introduction

These days, environmental problems have become one of the most important issues. Especially, exhaust gas of automobile is considered as the main culprit of air pollution and global warming. Therefore Hybrid Electric Vehicles (HEVs) or Electric Vehicles (EVs) are a topic of major interest among automotive industries.

Lithium ion batteries (LiBs) have high open circuit potential, energy density and low self discharge rate. Because of these advantages, LiBs are used in satellites, cellular phones, tablet PCs and etc. Furthermore, LiBs are considered as the most powerful energy storage system for HEVs and EVs due to these strong points.**[1]**

However, LiBs have many disadvantages, too. For example, when over-charging or over-discharging is occurred, Lithium metal is deposited on electrode surface. Lithium metal deposition reaction causes degradation of performance and internal short circuit. Reactions between electrolytes and electrodes produce flammable gases, too.

Most serious problem of LiBs is the excessive heat generation due to electrochemical reactions and ohmic resistance which causes thermal runaway and explosion of LiBs.

In HEVs and EVs, LiBs are placed most severe condition. LiBs in HEVs and EVs are exposed wide range of ambient temperature from -20°C to 40°C. Furthermore, Discharging and charging cycles are repeated with driving cycles. Therefore, LiBs in HEVs and EVs, produce heat during driving with cycling charging / discharging electrochemical reactions. High temperature of LiBs because of heat generation of LiBs or high ambient temperature, causes reduction of the performance of LiBs and decrease in life of LiBs too.

To avoid these problems, HEVs and EVs have thermal management systems in their battery systems. Thermal management system keeps the temperature of lithium ion battery pack in optimal range and the temperature of each cell equal to prevent temperature deviation between cells.**[2]**

Battery thermal management systems for HEVs or EVs are typically classified Air cooling system and Liquid cooling system**[3,4]**. Main part is a fan or blower for air cooling systems, and pump for liquid cooling system. Figure 1 shows schematics of air cooling system and figure 2 presents SIMULINK® model of lithium ion battery pack with air cooling thermal management system.

2 Modelling

We build the lithium ion battery pack model for EVs which includes electric model and thermal management system model of lithium ion battery pack. We modelled lithium ion battery pack of 50Ah lithium ion battery cells of SK innovation®.

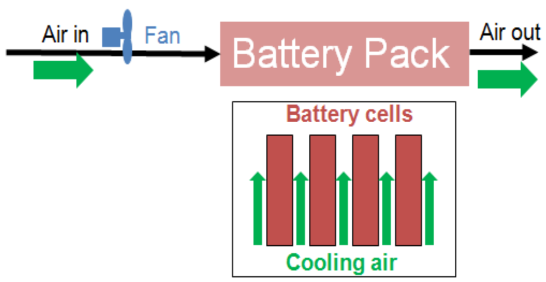

Figure 1. Air cooling schematics

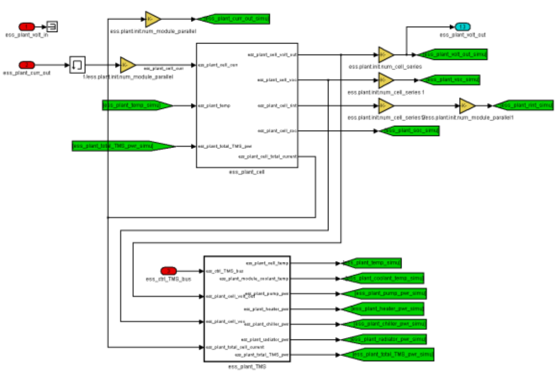

Figure 2. SIMULINK® model of lithium ion battery pack with air cooling thermal management system

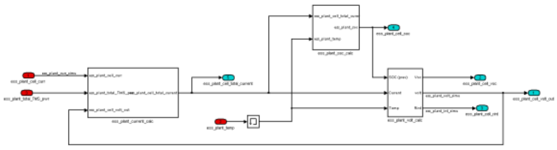

Figure 3 Battery electric model

2.1 Electric model of lithium ion battery pack

In battery electric model, we calculate the electrical characteristics of the lithium ion battery pack. We calculate the LiBs voltage and state of charge (SOC) in battery electric model. We use open circuit potential map and internal resistance map of the lithium ion battery cell from SK innovation®. Battery electric model is shown is figure 3.

To calculate the voltage of the lithium ion battery pack, we use open circuit potential, internal resistance and battery electrochemical properties. In lithium ion battery, there are 2 main voltage loss mechanisms. One is the ohmic voltage loss due to internal resistance of lithium ion battery cell. The other one is activation voltage loss because of electrochemical reactions which occur at the interface of electrodes and electrolyte. Therefore, we calculate the voltage as shown in formula (1)

$$V = n \times (V_{OCP} - IR_{internal} - \eta_{activation}) \quad (1)$$

Here, V_{ocp} is an open circuit potential of a lithium ion battery cell, $R_{internal}$ is an internal resistance of a lithium ion battery cell, and $\eta_{activation}$ is an activation loss of lithium ion battery cell.

We use Butler-Volmer equation to calculate the activation voltage loss of each cell for negative electrode and positive electrode.**[5,6,7]** Activation voltage loss is generated with electrochemical reactions at each electrode. We calculate the activation voltage loss is expressed in formula (2).

$$J_j = k_j c_{s,j,max} c_e^{0.5} (1 - x_{j,surf})^{0.5} x_{j,surf}^{0.5} f(\eta_j)$$
$$f(\eta_j) = \exp(\frac{0.5F}{RT}\eta_j) - \exp(-\frac{0.5F}{RT}\eta_j) \quad (2)$$

Here, k_j is a reaction rate constant of a lithium ion battery cell, C_e, C_s is a concentration of electrolyte and electrodes of a lithium ion battery cell, and $\eta_{activation}$ is an activation loss of lithium ion battery cell.

In this study, we calculate the SOC of lithium ion battery pack as shown in formula (3). SOC is decreased when a battery pack is discharged, current is positive.

$$SOC = SOC_{init} - \int I dt \qquad (3)$$

2.2 Thermal Management System model of lithium ion battery pack

Thermal Management System model of lithium ion battery pack is divided in two parts. One of them is for calculating the heat generation of lithium ion battery pack and the other one is for calculating the heat transfer from lithium ion batteries to cooling air.

In heat generation part, we build the model of heat generation from the lithium ion battery due to its internal resistance and electrochemical reactions. Ohmic heat is generated due to its internal resistance and activation loss heat is generated because of electrochemical reactions at negative and positive electrodes. We calculate the generated heat as expressed in formula 4. Figure 4 shows the SIMULINK® ® model of the heat generation.

$$Q_{gen} = I \times (V_{ocp} - V) + I \times V \times (1 - \eta_{coul}) \quad (1)$$

Here, V is a voltage of a lithium ion battery pack, η_{coul} is a coulombic efficiency of a lithium ion battery cell.

Heat transfer model calculates the temperature of lithium ion battery cell of each column. In SK innovation® air cooled lithium ion battery pack, cooling air passes through the flow channel between lithium ion battery cells in module. We calculate the heat transfer from lithium ion battery cells to cooling air and find temperature of air outlet and lithium ion battery cells. We calculate the temperature increase the Heat transfer model is presented in figure 5.

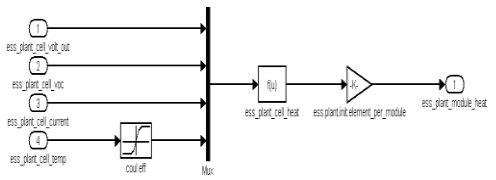

Figure 4. Heat generation model

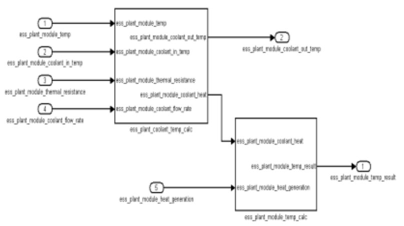

Figure 5. Heat transfer model

2.3 Cooling strategy

Thermal Management System needs electric power to maintain the temperature of the lithium ion battery pack in optimal range. Thermal management system uses electric power of the lithium ion battery and causes reduction of the SOC. Therefore, optimal strategy is very important to preserve the SOC of the battery pack and extend the available driving range.

In this research, thermal management system of the lithium ion battery pack for EVs of SK innovation® has an electrical fan to control the temperature of the battery pack.

We make the cooling strategy of the lithium ion battery pack with electrical fan. Cooling strategy is like below.

1. Compare battery temperature with ambient temperature.
2. If battery temperature is higher than ambient temperature, turn on the electrical fan.
3. If battery temperature is lower than ambient temperature, electrical fan must not turn on.
4. If battery temperature is higher than some specific temperature, electrical fan speed is increased. There are 4 electrical fan speed steps.
5. If battery temperature is lower than some specific temperature, electrical fan speed is decreased.

Cooling strategy is built in flow chart by SIMULINK®

3 Validations

After building the lithium ion battery pack thermal management system model, we validate the model with battery pack cycle experimental datum. SK innovation® gives the experimental results. As shown in figure 7, simulation results are well matched with experimental results. To protect the confidential of SK innovation®, exact numbers of axis are deleted.

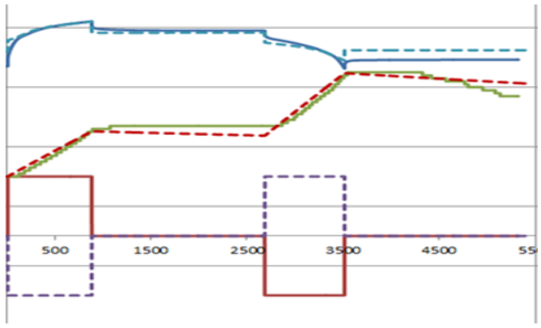

Figure 7. Validation of simulation results

Solid line is the experimental results and dashed line is the simulation results. Blue line shows the voltage of the battery pack and green line presents the temperature of the battery pack.

4 Conclusions

In this study, we build the lithium ion battery pack model with air cooled thermal management system. The following points are drawn from this study.

1. We build the lithium ion battery model including electrochemical characteristics. Activation loss due to electrochemical reactions is calculated by Butler-Volmer equation.
2. We made the cooling strategy of air cooled thermal management system. If temperature of battery pack is higher than temperature of ambient air, fan will be operated. Then, fan speed is determined by the temperature of the battery.
3. Air cooled thermal management system is modelled and validated in pack level. Simulation results are well matched with experimental results..

Acknowledgments

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