The Thermal Simulation Research of Lithium Ion Battery Pack

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Abstract. The thermal characteristic of the Lithium ion battery pack has a strong influence on the operation and maintenance. The thermal model of the 10kWh Lithium ion battery pack was developed. The temperature and velocity vector field of the running battery pack was studied through simulation by computational fluid dynamics software. The accuracy of the pack thermal model was proved by experiments.

Introduction

With the development of new energy, such as wind power, photovoltaic power generation, energy storage systems have become increasingly prominently important [1]. At present, Lithium-ion battery energy storage system is one of the largest energy storage systems which are most demonstrated and applied at home and abroad. In practice, in consideration of system operation management and routine maintenance, there is a need to not only effectively carry out power management [2,3], but also pay attention to the thermal management [4,5], in order to ensure that the battery is in a consistent temperature environment. The key to thermal management of battery pack is to establish a reasonable battery thermal model, verify its accuracy and then develop an effective thermal management strategy on this basis.

This paper used a simplified thermal model of a battery cell, built a thermal model of 10kWh lithium-ion battery pack through Computational Fluid Dynamics (CFD) and Computer Aided Design (CAD) software for solutions. Through analyzing temperature data from the operations of the battery pack, assembling the 10kWh lithium-ion battery prototypes and conducting experiments, the simulation results of a battery pack thermal model were verified.

Measurement of Thermal Parameters of Lithium Ion Batteries

The tested battery was a 60Ah lithium-ion battery manufactured by a Chinese company. Adiabatic accelerating rate (ARC) calorimeter of THT, a British company, was used to conduct the test of battery heat capacity with a test temperature range of 22 ℃ -57 ℃. The Model TP500s of THT thermal conductivity tester was used to measure its heat conductivity coefficient.
Table 1. The thermal Parameters of Lithium Ion Batteries.

| Specific heat (Cp) / J·K⁻¹·g⁻¹ | Thermal conductivity (K) / W·Mk⁻¹ |
|---------------------------------|----------------------------------|
| 1.033                           | 1.399                            |

**Measurement of the Thermal Value**

THT’s adiabatic accelerating rate calorimeter (ARC) was selected to conduct tests on the battery’s 0.5C constant current charge and discharge heat. Test conditions: (1) 30A constant current charging heat: the charging voltage 2.5V-3.65V, and charging current 30A; (2) 30A constant current discharge heat: discharge voltage of 3.65V-2.5V, and the discharge current of 30A.

![Figure 1. Curves of Power and Current of Charging and Discharging.](image)

Figure 1 is the battery’s 0.5C heat value and charge & discharge curve diagram. The heat value curve tested by ARC consists of two heat value curves in the circulation. The battery’s heat value presents regular changes accompanied by its charging and discharging of power.

**Simulation and Experimental Analysis**

Modeling and design were based on SolidWorks company’s SolidWorks software. CD-adapco Company’s STAR-CCM+ was used for CFD. This paper adopted continuum mechanics algorithm, conducted FSI heat transfer simulation calculation, during which the main physical issues involved were slit cavity convective heat transfer and heat transfer between solids. The equations are the following:

Mass conservation equation:

\[
\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_k}(\rho V_k) = 0
\]  

(1)

Momentum equation:

\[
\frac{D V_j}{D t} = -\frac{1}{\rho_0} \frac{\partial (P - P_0)}{\partial x_j} + \nu \frac{\partial^2 V_j}{\partial x_k \partial x_k}
\]

(2)
Energy conservation equation:

\[
\frac{DT}{t} = a \frac{\partial^2 T}{\partial x_i \partial x_i} + \frac{\nu}{c_p} \Phi_v
\]  

(3)

Standard two equation turbulence model of two equations:

K equation:

\[
\rho \frac{\partial K}{\partial t} + \rho u_j \frac{\partial K}{\partial x_j} = \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu_t}{\sigma_s} \right) \frac{\partial K}{\partial x_j} \right] + \mu_t \frac{\partial u_j}{\partial x_j} \left( \frac{\partial u_i}{\partial x_i} + \frac{\partial u_i}{\partial x_i} \right) - \rho \varepsilon
\]  

(4)

\varepsilon\text{ equation:}

\[
\rho \frac{\partial \varepsilon}{\partial t} + \rho u_j \frac{\partial \varepsilon}{\partial x_j} = \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu_t}{\sigma_s} \right) \frac{\partial \varepsilon}{\partial x_j} \right] + \frac{c_\varepsilon}{k} \mu_t \frac{\partial u_j}{\partial x_j} \left( \frac{\partial u_i}{\partial x_i} + \frac{\partial u_i}{\partial x_i} \right) - \frac{\varepsilon}{k} \mu_t + c_\mu \rho K^2 / \varepsilon
\]  

(5)

The simulation object is a battery pack of 48 domestically-made 60Ah lithium-ion batteries composed of 3 parallel connections and 16 series connections. The cooling mode is set to wind cooling. Figures 2 (a), (b) are a schematic diagram of the battery model and the simulation model. Two parallel rows of cells arranged in sequence with splints fixed on both sides. The front of the cell pack is a rectangular drawing air inlet and the rear end consisted of the simulation model of five cylinders fans.

Figure 2. (a) the Diagram of Battery Model, (b) the Diagram of Simulation Model.

FTV4-300-100 produced by US Bitrode was selected to test the battery pack on charge and discharge at constant current. The module was placed in SDJ/W580, a multi-purpose high temperature chamber produced by Chongqing Sida Experimental Equipment Co., Ltd., with a test environment temperature of 20 °C. K-type thermocouple produced by US Company Omega was used and placed at the battery’s lug. A HIOKI8422-51 logger produced by Japan HIOKI Company was used to measure and record the battery surface temperature, with a measurement accuracy of ± 0.1 °C.
Figure 3. (a) the Diagram of Simulative Temperature for the Battery Pack, (b) the Diagram of Measured Temperature for the Battery Pack.

Figure 3 (a) is a battery pack’s simulation temperature curve. The battery showed regular changes accompanied by battery pack’s charge and discharge at surface temperature. At the discharge phase, the battery temperature begun to rise. The highest temperature occurred at the end of battery discharge. During the standing time, the temperature of the cell pack reduced. At the beginning of charging, the cell had a short initial endothermic process, which made the battery temperature rose slowly. The heat value increased to temperature extremes and then decreased. Thus, the maximum value of the battery temperature was not at the last charging stage. The temperature of the front battery was significantly lower than that of the rear battery. During the operation, the battery pack’s maximum temperature was 23.9 °C with a field temperature difference of 0.8 °C ~ 1.5 °C. Figure 3 (b) was a schematic view of the actual temperature of the battery pack. During the operation, the battery pack’s maximum temperature was 24.2 °C with a temperature difference of 1.0 °C ~ 2.3 °C within the battery pack. The measured temperature and the simulated temperature shared the same temperature change trends. The temperature of the front battery was below that of the rear battery. The measured value and the simulated value was similar, which testified the accuracy of the simulation and verified the reasonability of the design. As can be seen from the above results, the simulation accurately reflected the distribution of temperature field and flow field within the battery pack.

Conclusion

Through CFD software, simulation analysis was conducted on battery pack’s temperature changes under two conditions at 0.5C constant current charge-discharge cycle, and accurately reflected the battery pack temperature field and flow field under working conditions. At 0.5C constant current charge & discharge conditions, the battery pack’s maximum simulation temperature was 23.9°C with the temperature differences within 0.8 °C ~ 1.5 °C. The highest measured temperature was 24.2 °C with a temperature difference of 1.0 °C ~ 2.3 °C. The method can accurately simulate the battery pack’s temperature field under working condition, simplify the structure of the design process and improve the safety of lithium-ion battery energy storage system.
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References

[1] P.C.D Granado, Z. Pang, S.W. Wallace. Synergy of smart grids and hybrid distributed generation on the value of energy storage. Applied Energy, 2016, 170: 476-488.

[2] E. Reihani, S. Sepasi, L.R. Roose, M. Matsuura. Energy management at the distribution grid using a Battery Energy Storage System (BESS). International Journal of Electrical Power & Energy Systems, 2016, 77: 337-344.

[3] X. Feng, H.B. Gooi, C.S. Huai. Capacity fade-based energy management for lithium-ion batteries used in PV systems. Electric Power Systems Research, 2015, 129: 150-159.

[4] A.H. Said, J.R. Selman. Thermal modeling of secondary lithium batteries for electric vehicle/hybrid electric vehicle applications. Journal of Power Sources, 2002, 110(2): 341–348.

[5] Y.L. Bor, P.B. Keith, G.Y. Xiao. Advanced integrated battery testing and simulation. Journal of Power Sources, 2002, 110(2): 330–340.