Advanced Thermal Design Of Lithium-Ion Battery For Grid Energy Storage Applications

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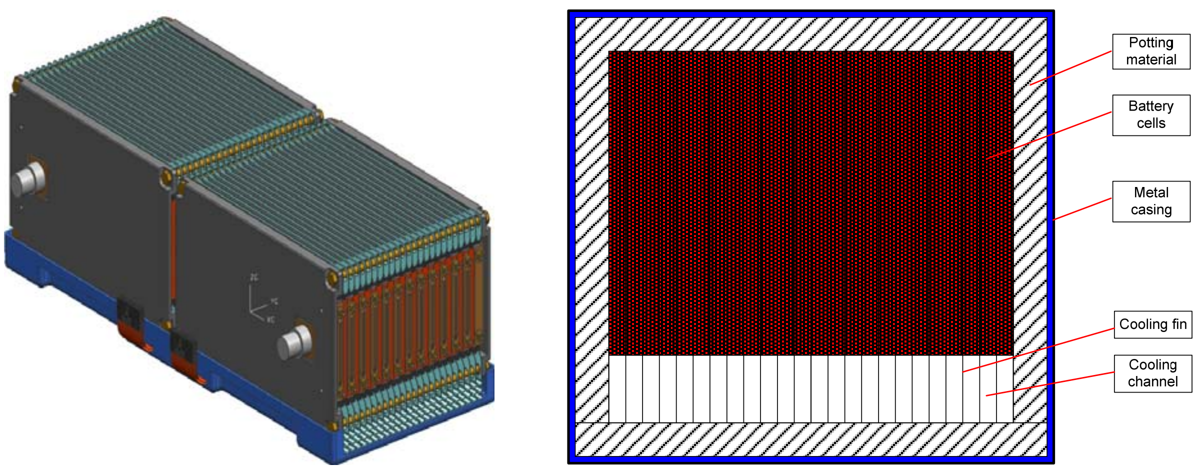
Lithium-ion batteries offer potential advantages in energy density, power density, and cost for use in renewable energy and distributed energy systems. One of the challenges imposed by lithium-ion battery is the thermal management. The best operating temperature of lithium-ion battery is from -10°C to 50°C. An effective thermal management system is critical to maintain the health and life span of the battery. A good thermal management system starts with accurate prediction of the thermal conditions of the battery. This paper is aimed to design an effective thermal management system for the lithium-ion battery pack, including estimating the thermal loss of the battery pack based on electric characteristics and experiments; predicting the temperature rise of the battery pack based on the test results of a single cell, and modeling the temperature gradients of the battery pack under different operating conditions.

This paper presents the study on the thermal modeling of a lithium-battery pack. The pack consists of 48 lithium-ion battery cells. All the 48 cells are electrically connected in series to provide needed voltage. The mechanical arrangement of the 48 cells is shown in Fig. 1 (a), where the pack is divided into two groups. Each group has 24 battery cells stacked together with aluminum cooling fins in between the cells. Fig. 1 (b) further shows the cross section of each battery group. The battery pack is fitted into a metallic case, with thermal insulation inserted between the battery and the case. The cooling fins run through the battery and expends beyond the battery at the bottom to form a cooling channel to allow cooling to flow. Therefore, it can be assumed that there is no heat exchange between the ambient and the battery. Battery heat is carried out by the cooling fins. The cooling air takes away heat from the cooling fins.



(a) (b)

Fig. 1. Arrangement of the lithium-ion battery pack. (a). Battery without the casing. (b). Cross section of the battery pack. The cooling fins run between battery cells and extend beyond the battery. The battery pack is fitted into a metallic case, with thermal insulation inserted between the battery and the case.

In order to determine the heat generation in the battery packs during operation, we performed test on a single cell during rated-current charge and discharge. The battery cell under test was placed in an ambient without external heating or forced air disturbance. The temperature rise of the cell during cell charge and discharge is show in Fig.2. The flat temperature profile, after a long period of operation, indicates that a steady state is reached. Examination of the thermal history shows that the temperature difference is 32.92°C – 25.22°C = 7.70°C, when steady state is reached. This averaged temperature is calculated using the average of temperature readings over one cycle. Since the test cell is exposed in the air without any forced air cooling, there only exists radiation and nature convection. The estimated heat in the cell was 2.7W. The heat generation can also be calculated using the battery impedance and charge rate. The measured cell impedance is 3.263mΩ. The calculated loss of the battery cell is 4.08W during discharge and 1.02W loss during charge. The average loss is

(4.08 * 156 seconds + 1.02 * 312 seconds) / (156s + 312s + 5s + 5s) = 2.0 W. This is lower than the estimated heat of 2.71W. The difference could be introduced by the calculation error and inaccuracy of the internal impedance. Besides, this loss may not include the conduction loss in the electrodes.

The 48-cell battery pack is analyzed using both analytical and numerical method. The temperature of the battery during normal charge/discharge is shown in Fig. 3. The numerical and analytical results are compared in Table I. It can be seen that the results from the two methods are consistent.

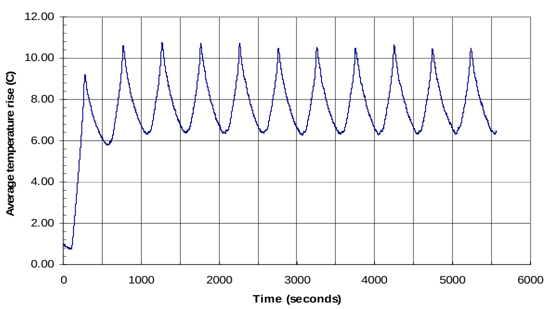


Fig. 2. Temperature rise of a single battery cell as a function of time during constant charge/discharge.

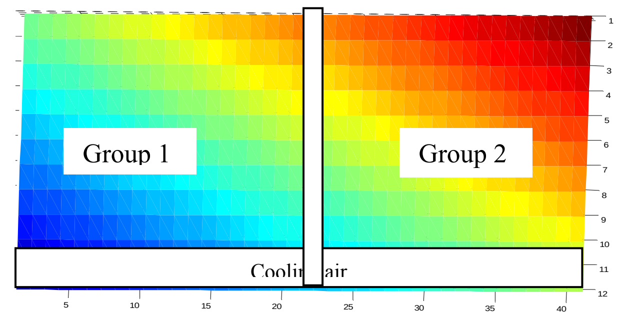


Fig. 3. Battery temperature rise. X-axis: length direction of the battery; y-axis: height of battery (in cm).

We also studied the effect of fin length. Table II shows the temperature rise for fin length of 5mm, 10mm, 15mm and 25 mm. It can be seen that for the given conditions, only 25mm will be able to satisfy the operating requirement.

Table I Comparison of Temperature Rise Calculated Using Analytical and Numerical Methods

	Numerical	Analytical	Difference
Lowest Temperature rise (°C)	11.0	10.8	1.8%
Maximum Temperature rise (°C)	16.4	17.3	9.5%
Temperature gradient (°C)	5.4	6.5	1.1°C
Inlet/outlet air temperature difference (°C)	16.3	15.8	3.2%
Highest pack temperature (°C)*	40.7	39.6	2.8%

Table I Temperature Rise with Different Fin Size

Fin height	5mm	10mm	15mm	25mm
Maximum temperature rise (°C)	43.32	34.23	30.08	23.74
Lowest temperature rise (°C)	33.52	21.97	16.70	10.81
Average Temperature rise (°C)	38.42	28.10	23.39	17.28

Conclusions

This paper presented the thermal analysis and design of lithium-ion battery for potential PHEV applications. The analytical calculations and numerical simulations show that in order to effectively cool the battery pack, a minimum 25mm cooing fin is needed. Transient analysis shows that it takes long time to cool battery to below acceptable operating temperature under extreme initial temperature. The prototype is being developed and further experiments will be carried out to validate the design.

Acknowledgement

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