A Novel Active Air Cooling Strategy for Large-scale Lithium-ion Battery Energy Storage Systems

by

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ABSTRACT

For thermal management of Li-ion battery packs, much effort has been expended on the development of various cooling strategies such as air cooling, liquid cooling, phase change material cooling, etc., to achieve desired battery temperature control targets with low parasitic power consumption and low thermal management system manufacture, operating and maintenance cost. In the analysis and comparison of these cooling methods, the heat generation rate of the battery pack is usually assumed as a constant value ; however, according to research on the Li-ion heat generation rate, the heat generation rate of Li-ion battery changes substantially with the battery charge and discharge rates, depth of discharge (DOD), and battery temperature since the electrical resistance and entropic heating values of batteries vary significantly with different discharge rates and DODs. From the measurements and calculations of various investigators, during the charge cycle the battery heat generation rate is almost negligible (around 1 W/L even at 1C charge rate); while the battery would release large amounts of heat at high discharge rates (around 20 W/L at 1C discharge rate) because of the reversible chemical effects.

In this thesis, a novel air cooling strategy for the thermal management of Li-ion battery packs is proposed to take advantages of these substantial changes of heat generation rate of battery batteries during duty cycles to reduce the parasitic power consumption of a thermal management system. In this air cooling system, a variable cooling fan is used for the forced convection cooling of batteries during the discharge cycle when battery heat generation rates are high. While in the charge cycle, when the heat generation rate is negligible, natural convection is an efficient cooling method. The ON/OFF of the cooling fan can be actively controlled by the time or battery temperature to further reduce the consumed power.

A transient lumped thermal model of an air-cooled battery system is developed using MATLAB to conduct a parametric investigation on the thermal management methodology during typical or artificial duty cycles; the thermal management method is evaluated for its efficiency and performance. A commercial computational fluid simulation (CFD) software, ANSYS Fluent, is used to validate the lumped capacitance assumption and to evaluate the thermal performance of the battery energy system designed by Ultralife® company.

The MATLAB simulation results of the battery pack under various duty cycles scenarios and cooling conditions demonstrated that the cooling fan parasitic energy consumption can be significantly reduced with the proposed fan control method. Forced cooling air velocity and ambient temperature showed substantial effects on the battery temperature profile and parasitic energy consumption. For a given duty cycle, there may exist an optimum operating air velocity, when the battery temperature control target and minimum parasitic energy consumption can be achieved. The temperature rise of the ambient air could significantly increase the maximum battery temperature and parasitic energy consumption in the cycle. The maximum battery temperature will inevitably surpass the maximum allowable battery operating temperature when the ambient air temperature is higher than the maximum allowable operating ambient air temperature in that cooling condition. An HVAC system would be recommended for the battery packs working in high ambient temperature conditions.