

Experimental investigation and thermal modelling of a series connected LiFePO₄ battery pack

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ABSTRACT

The present paper reports the results from modelling and experimentation with a lithium-ion battery pack operating at room temperature and under varying discharge rates. The variation in the internal resistance of the cell with change in the temperature is investigated experimentally. The prismatic Li-ion battery pack is discharged at 1C, 2C, 3C and 4C and significant parameters, such as pack voltage, temperature, and state of charge, are obtained. This is accomplished by connecting three LiFePO₄ 20 A h capacity prismatic batteries in series and applying 18 thermocouples at various locations on the surface of all three cells. The results show that there is a significant increase in battery surface temperature with an increase in discharge rate. The highest average surface temperature of the battery pack (56.5 °C) is observed experimentally at a 4C discharge rate, and the lowest (30.7 °C) at 1C based on modelling. Similarly, the maximum total heat generation (59.2 kJ) is observed at 4C experimentally and the minimum (37.5 °C) at 1C from modelling. A comparison of the modelling results with the experimentally determined temperature, voltage and heat generation shows good agreement. Also, the internal resistance of the cell is observed to increase as the state of charge decreases, and to decrease with increasing cell temperature.

1. Introduction

Recently, electric vehicles (EVs) and hybrid electric vehicles (HEVs) have received much attention in the automotive sector as options for reducing CO₂ emissions [1,2]. Batteries are a significant part of the powertrain in electric and hybrid electric vehicles. Today, the Li-ion battery is considered to be one of the best choices for EVs, because of its superior energy and power density, high life cycle, no memory effect and low self-discharge [3–7]. Prismatic cells are most widely used in EVs and HEVs, partly because they permit efficient space utilisation using a layered approach [8].

In an electric vehicle, the battery pack is made up of a combination of various modules, each consisting of cells connected in series and parallel to achieve the required current and voltage. Although Li-ion batteries have various advantages, they have the drawback of generating significant heat during charging and discharging. Operating under ambient temperatures can adversely affect battery performance in a situation where the battery pack is not properly insulated. Most Li-ion battery manufacturers provide an operating temperature range for the battery, ranging from –20 °C to 60 °C. However, the operating

temperature should not exceed 40 °C nor should it drop to below 5 °C in order to achieve full battery lifespan. Operating at low temperatures (< 20 °C) increases the internal resistance of the battery, leading to a decrease in available capacity, while operating at high temperatures (> 45 °C) can cause safety issues and ageing problems [9–12]. Therefore, it is recommended to maintain the battery pack temperature within a range of 25 °C–40 °C to minimise ageing issues and to avoid thermal runaway.

Temperature can adversely affect the discharge rate and cycle life of the battery. It can also reduce the total capacity and power density over time. When an interior cell fails, the energy in the cell suddenly flows to its neighbouring cells, raising the temperature significantly to as high as 450 K. This can create local hot spots and cause battery pack failure. This phenomenon of thermal runaway is damaging to the battery and mainly caused by stressful operating conditions [13]. Therefore, it is recommended to maintain the battery pack temperature within a range of 25 °C–40 °C to minimise ageing issues and to avoid thermal runaway [14].

To understand the thermal behaviour of batteries and the impact on battery performance and life, the temperature distributions and heat

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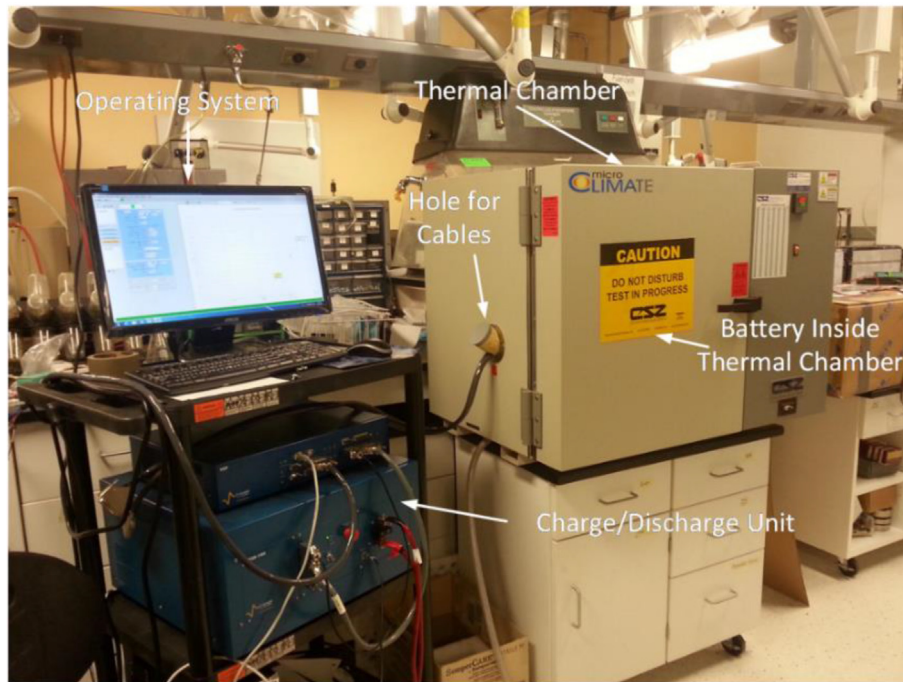
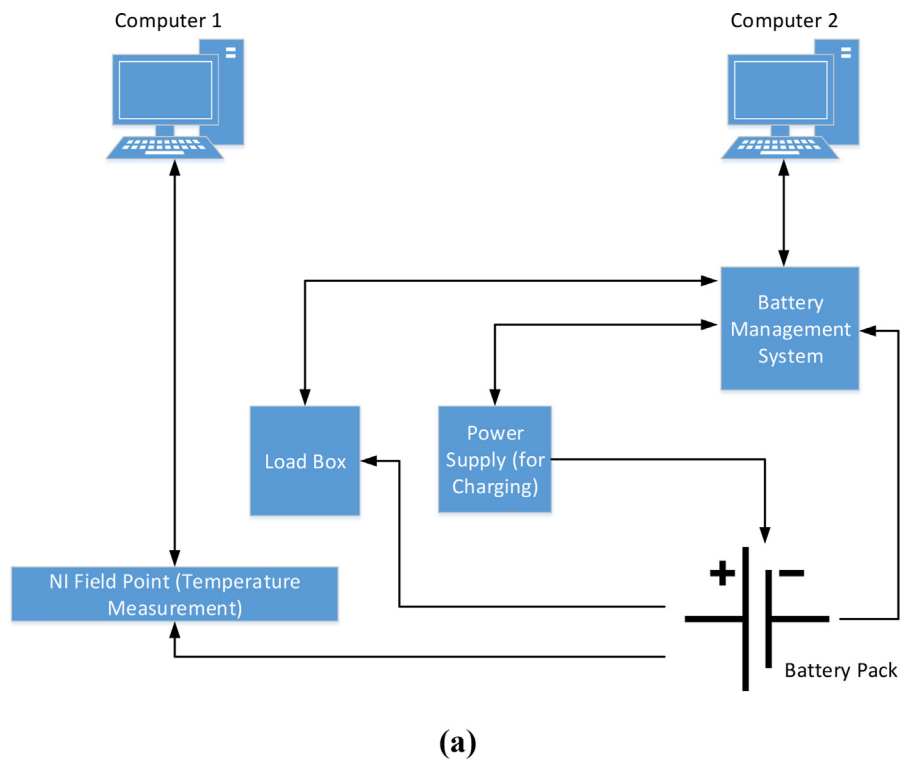


Fig. 1. Experimental setup; (a) line diagram of experimental setup for battery testing, (b) experimental setup for resistance measurement.

generation profiles of batteries need to be known at various charge and discharge rates. A number of studies have been conducted in this area. Some of these take simplified approaches, treating thermal management of lithium-ion batteries as simple and one dimensional with constant heat generation and constant properties [15–18].

Saito et al. [19] experimentally investigated heat generation for lithium-ion cells in the overcharge condition and showed that the heat generation during overcharging is directly proportional to the charging

current. Yang et al. [20] uses pseudo two dimensional model of the lithium-ion batteries to calculate the rate of heat generation and also investigate the thermal behaviour of the battery with air cooling. In another study, an electrochemical-calorimetric method was used by Al-Hallaj et al. [21] to evaluate the thermal behaviour and performance of several cylindrical and prismatic Li-ion cells. It was shown that the heat dissipation rate is directly related to the rate of discharge (C-Rates), and that structural transformation in graphite anode material or phase

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