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Study and identification of the thermo-electric behavior of lithium-ion batteries for electric vehicles

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Abstract

In this paper, the study and the modeling of a lithium-ion battery cell is presented. A programmable electronic load was laboratory designed and realized in order to reduce the cost of the total equipment. The testing system is supplemented with a commercial programmable power supply. This dedicated laboratory equipment can be used to apply cycles according to user defined current profiles. Some tests were performed on the battery cell. The acquired data allowed to carry out the battery modeling and the parameters identification procedure. Finally, the mechanical and the thermal phenomena to which a battery is subjected are presented and discussed.

Keywords: lithium-ion battery; battery testing equipment; battery modeling; parameters identification; hybrid vehicles; thermal issues; mechanical failure

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1. Introduction

The first Electric Vehicle (EV) was invented in 1834 but then EVs vanished from the scene because of the development of Internal Combustion Engine Vehicles (ICEVs). Nowadays, due to the environmental issue, the interest on EVs and on Hybrid Electric Vehicles (HEVs) is growing again thanks to their lower pollutant emissions. Chan (2002) shows that new studies and technological proposal are continuously involving the automotive field, and

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more recently also the working machinery field as presented by Somà et al. (2016). In the latter, Mocera and Somà (2017) underline that lots of attention has to be put on the architecture design depending on the power requirement of the specific application. The main difference between an ICEV and an EV or HEV is the presence of a battery pack used to power the vehicle. The battery pack is a system of single battery cells connected in series to increase the voltage and in parallel to increase the capacity. Bandhauer et al. (2011) shows that the main limitation to the spread of larger fleets of electric vehicles on the mass market is still related with safety, cost, lifetime and operating temperature ranges performance.

To guarantee the best working conditions, voltage, current and temperature of the single cells are handled by an electronic unit called Battery Management System (BMS) as presented by Barreras et al. (2016).

Traction batteries need characteristics such as high energy density and power density. The Ragone plot represented in Polleta et al. (2012) shows that, among the established technologies, lithium-ion and lithium-polymer cells are the one which best satisfy these requirements. Other advantages addressable to Li-ion batteries are the high cell potential and the high charge/discharge rate as presented by Nitta et al. (2015). However, there are still some drawbacks and they are mainly related with cost, safety, lithium reliability and cycle life. Nevertheless, Conte (2006) says that lithium based cells seem to be the pathway for the HEVs' future.

Further distinction must be introduced within the lithium-ion batteries. A first classification can be done according to the cell's shape and size. A battery cell can be manufactured in different shapes, typically cylindrical, prismatic and pouch. Cylindrical cells have the lowest energy density compared to the others, however they are the cheapest to be produced so they are still widely used also in the automotive field. Prismatic cells have a higher energy density and are characterized by and external hard case. Pouch cells are flexible, can be produced in different formats and are characterized by the higher energy and power density. Since electric vehicles are a focus of interest, the industry trend is toward larger batteries. The design of larger batteries requires to reduce the costs and improve safety, as presented by Bandhauer et al. (2011). In fact, although large cells (prismatic and pouch cell) are lighter and more compact with respect to the energy amount they can store, their cost is higher, the quality of the cells is harder to be guaranteed and the thermal management is a very sensitive aspect because they can store a large amount of energy. On the other hand, smaller cells are favourable for the thermal management and the cost effective. However, in order to obtain the battery pack voltage and capacity needed, many cells must be electrically connected, implying higher chances of failure and energy lost especially due to contact resistance. Therefore, Saw et al. (2014) say that appropriate considerations are required to select the appropriate cell size to build a battery pack for a certain application.

A second classification can be made according to the materials present inside the battery. The main elements inside a battery are the anode, the cathode, the separator between the electrodes and the electrolyte. Nowadays the materials composing the battery electrodes are object of lots of research studies such as Passerini (2016). Most of the research on these batteries has been related to finding the best electrodes material in terms of specific energy, specific power, terminal voltage and cycle life, but with relatively little attention paid to thermal management as underlined by Bandhauer et al. (2011). Nitta et al. (2015) present the typical materials employed for the cell's electrodes. For the anode they are Graphite and more recently Lithium Titanate (LTO). Among the structures used in the cathodes there are Lithium Cobalt Oxide (LCO), Lithium Manganese Oxide (LMO), Nickel Manganese Cobalt Oxide (NMC), Nickel Cobalt Aluminium Oxide (NCA) and Lithium Iron Phosphate (LFP). Conte (2006) points out that there is not a perfect battery with the best performance, but an appropriate compromise must be identified according to the application. Many combinations of anode and cathode materials can be used. Among the commercialized cells, a dominant position is awarded by the LFP-graphite batteries that guarantee the best results in terms of both safety and duration. Bandhauer et al. (2011) says that the cathode material $LiFePO_4$ has been shown to exhibit a superior thermal stability with respect to other chemistries, due to a smaller exothermic heat release.

In the last years, the need to study batteries in real working conditions has increased the demand for high specific testing equipment. With high energy batteries, testing equipment must handle high current rates and the costs connected to these devices are consistent. To contain the costs, some attempts were done to build devices able to discharge batteries like Propp et al. (2015), but always with low current and for low energy batteries. In fact, increasing the current, the heat to be dissipated grows too, and it is necessary to properly dissipate heat in order the system to work in safe operating conditions.