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Critical review of state of health estimation methods of Li-ion batteries for real applications

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ABSTRACT

Lithium-ion battery packs in hybrid and electric vehicles, as well as in other traction applications, are always equipped with a Battery Management System (BMS). The BMS consists of hardware and software for battery management including, among others, algorithms determining battery states. The accurate and reliable State of Health (SOH) estimation is a challenging issue and it is a core factor of a battery energy storage system.

In this paper, battery SOH monitoring methods are reviewed. To this end, different scientific and technical literature is studied and the respective approaches are classified in specific groups. The groups are organized in terms of the way the method is carried out: Experimental Techniques or Adaptive Models. Not only strengths and weaknesses for the use in online BMS applications are reviewed but also their accuracy and precision is studied. At the end of the document a potential, new and promising via in order to develop a methodology to estimate the SOH in real applications is detailed.

Contents

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1. Introduction

The world is facing huge challenges. On the one hand, the world's population has already reached 7 billion and may rise to 10 billion in the coming decades [1]. On the other hand, technology is improving incredibly rapidly. This mixture means that the need for energy is increasing and furthermore, in an unpredictable way. Due to these two aspects, the doubt about the amount of accessible energy in the near future is a global concern. The impact of population growth and technological improvements which have to surely satisfy the needs of people now and in the future is becoming a threat.

Energy is produced by fossil fuels, nuclear energy or by renewable energies. The problem with fossil fuels is that they are limited and they took millions of years to create. Moreover, they affect the atmosphere with the CO_2 emissions they produce. Nuclear energy, in contrast, has a very low rate of gas emissions, but it is not easy to deal with the waste products; it produces due to their negative impact on our health and our environment. Regarding renewable energies, their intermittency makes them inefficient. A dependency on them cannot be created due to the impossibility of using them when they are needed.

Via the use of electrical storage, according to the U.S. Energy Department, the efficiency of generation facilities could increase by 40% and in turn would greatly reduce the dependence on polluting and inefficient power plants [2]. It could also drastically reduce the number of brownouts and blackouts thanks to the presence of the energy reserves.

The range of different Energy Storage Systems (ESS) is very wide, taking part different chemistries and cells formats. For many years, nickel–cadmium technology has been the only suitable battery for portable equipment from wireless communications to mobile computing until Nickel Metal Hybrid and Li-ion batteries emerged in the early 1990s. Today, Li-ion is the fastest growing and most promising battery technology. Li-ion technology is widely used in consumer low power products in the field of electronics such as cell phones and laptops and in high power applications such as electric vehicles, trams, bicycles, etc. It has rapidly become a standard power source and battery performance continues to improve so that it is possible its use in applications that demand more power. The main advantages of Li-ion batteries, are the high energy density (23–70 Wh/kg), the very high efficiency (near 90%) and the relatively long cycle life (3000 cycles at 80% depth of discharge) [3,4].

For example in transportation applications, like in electric or hybrid vehicles in order to cover the needs of fuel saving and ecological aspects, new improved functions of the vehicle are required. Including too safety, comfort, reliability and vehicle availability issues. The electric control and the powered systems for accelerating, braking, steering and stabilization need a reliable supply of electrical energy. Furthermore, the planned generation of electrical energy, an adequate storage, and early detection of possible restrictions of reliability must be managed by the battery monitoring system allowing the implementation of actions by the energy management unit well in advance, while the driver does not need to be involved at all [5]. In order to use an ESS covering all these aspects, a BMS must be used. The BMS is an electronic system which manages the operational mode of a battery to ensure and guarantee its safe operation mode. Basically this system is the one which protects the overall system and, based on its diagnostics, provides the optimal performance management of the energy storage.

As part of the diagnostic approach, the battery management system performs the on-board SOH estimation. SOH is a metric to evaluate the ageing level of batteries, which often includes capacity fade and/or power fade. It gives very useful information for predicting when the battery should be removed. If the performance of the battery is not normal it should be reflected in this parameter. It is not easy to estimate this state as it is not possible to perform a direct measurement. So that different estimation methods have been studied in this document in which their advantages and drawbacks are compared. The state-of-art review of literature summarized in this document points out that in general there is a lack of an explicit sensitivity evaluation of the SOH estimation methods. Furthermore, the process of developing a complete SOH estimation model (design, parameterization, implementation and validation) is not exhaustively described.

2. SOH estimation methods

The commercialization of electric and hybrid vehicles leads to an increasing demand for long life time batteries. Knowing the SOH can be used to recognize an ongoing or a sudden degradation of the battery cells and to prevent a possible failure of the electric system and, accordingly, the vehicle. Even though the importance of the SOH is really high, still does not exist a consensus in the industry or in the scientific community on what SOH is and how should be determined. It is a parameter that reflects the present condition of the battery cell described in percentage, being the 100% a fresh cell. In one hand when the capacity is decreased until 80% of the initial rated capacity the battery is considered not usable for an electric vehicle and should be removed. On the other hand, the increase of the internal resistance can be in some cases higher than the decrease of the battery capacity. The estimation of the battery SOH has to take into consideration both; battery capacity fade and impedance increase.

Unfortunately, Li-ion batteries are complex systems to understand, and the processes of their ageing are even more complicated. Capacity decrease and power fading do not originate from one single cause, but from a number of various processes and their interactions. Moreover, most of these processes cannot be studied independently and occur at similar timescales, complicating the investigation of ageing mechanisms. Ageing mechanisms occurring at anodes and cathodes differ significantly [6–10]. On the one hand, it is studied that dominant ageing mechanisms on anodes are caused by Solid Electrolyte Interface (SEI) formation which causes a significant increase of the impedance. This effect occurs mainly in the beginning of cycle life. Secondly, when loss of lithium in the active carbon takes place, it leads to self-discharge and capacity fades. Also, lithium metal plating contributes to an accelerated ageing causing capacity fade and power fade. The lithium metal plating may occur when the batteries are charged at low temperatures ($<0\,°C$) and/or at high current charge rates, whereby, the process of lithium ion through the negative electrode decreases and typical metal oxide parts take place on the surface of the electrode. Lithium plating results to less active material and thus the battery capacity decreases and the battery impedance increases as a consequence. On the other hand, cathode materials are affected significantly by both performances, cycling and