Integration of Advanced Diagnostic Capabilities in Battery Management Systems

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Within the BATMAN project, CSEM developed an innovative battery management system (BMS), capable of carrying out online electrochemical impedance spectroscopy (EIS), a battery diagnostic technique capable of determining the state of health (SOH) of Li-ion cells precisely and in a regular manner. Moreover, the prototype integrates a power switching architecture to bypass individual Li-ion cells in a battery. This architecture enhances the performance of battery packs in electric vehicle and stationary storage systems through more precise SOH estimation and improved cell balancing.

The performance of battery energy storage systems, both in electric vehicles and for stationary applications, is highly dependent on the battery management systems (BMS). These, among other tasks, must estimate the SOH of each Li-ion cell in the battery pack and determine their balancing strategy. The computation of SOH typically requires dedicated time-consuming off-line tests that can be carried out only occasionally. The absence of a reliable online SOH estimation method forces the designers of battery packs to make conservative choices to ensure pack safety, increasing the pack weight and volume. Moreover, different cells in a pack may degrade with different pace. Since the operation of a pack is limited by its weakest cell, this has a detrimental effect on the pack performance.

Within BATMAN, CSEM designed, fabricated and tested a set of cell management boards tackling these issues by introducing three innovations: 1) the capability to carry out EIS on each cell during pack operation, in order to get real-time information about the cells' degradation; 2) the capability to bypass individual cells within a battery module for increased reliability and smarter balancing (i.e. balancing optimizing battery lifetime); 3) the development of supervisory electronics at cell level rather than centralized, i.e. a "cell management system" (CMS) concept. Figure 1 shows a detail of such prototype. It consists of a small module composed by 8 200Wh NMC pouch cells, each equipped with its own CMS. Each CMS is composed of a custom PCB hosting an ST Nucleo board equipped with an STM32 microprocessor. The latter embeds the firmware developed to carry out conventional BMS tasks (such as voltage and temperature measurement and safety checks) as well as implementation and control of the mentioned features.

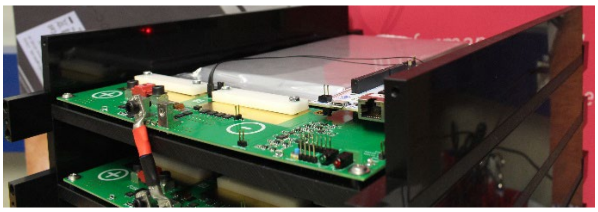

Figure 1: BATMAN prototype.

Online EIS

The EIS is carried out by subjecting the battery to a sinusoidal excitation signal spanning from 1 kHz to 10 mHz. Frequencies in the sub-Hertz domain contain important information about the degradation of the battery and are therefore relevant for estimating the SOH. The impedances at the highest frequencies can instead be exploited to estimate the internal temperature of the cell. Figure 2 shows the results of EIS testing carried out with the BATMAN CMSs. The results were compared with reference impedance values collected on the same cells with a Biologic BCS815 battery tester. Although a resistive shift of about 1.5 mOhm is present, the impedance curve shows the expected general behaviour. Moreover, the results show good consistency over repeated tests, confirming the reliability of the measurements. For frequencies up to 100 Hz, the average coefficient of variation of the measurements is of about 2%.

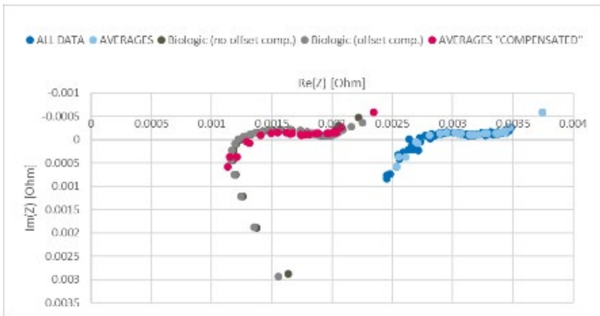

Figure 2: EIS results.

Cell bypass and lifetime balancing

The bypassing capability is achieved by integrating, in each CMS, MOSFET transistors that can insert the cell in the high-current path or bypass it. It has been validated for currents up to 45 A. Switching delays have been calibrated to avoid harmful cell conditions and minimize voltage and current transients.

Such switching feature will be exploited in future developments of the platform in order to demonstrate the concept of lifetime balancing: individual cells within the module carrying its electrical load for fractions of the operating time that are related to their SOH. By this modulation, it will be possible to maintain a uniform level of degradation within a string and avoid a shortened module life due to one "weak" cell.

CMS concept

The features 1. and 2. are enabled by moving of the intelligence of the battery management from a centralised BMS to management entities integrated in every cells. This offers several advantages. It enables the integration of an increased number of sensors without a corresponding increase in system complexity. Secondly, it simplifies the repurposing of individual cells in second-life applications since all information relevant to their usage is now stored on the cells themselves. This solution is particularly suited for pouch cells with high capacity (>200 Wh), which are being deployed more and more frequently in battery packs. The existing drawbacks are in the cost and communication requirements, which are being tackled by ongoing development projects.

The BATMAN prototype will serve as platform for testing and developing in a realistic setup further aspects of battery management such as model-based state-of-charge (SOC) estimators, charge and lifetime balancing strategies. Further developments of this CMS platform will be carried out within the MIP project ROBIN (development of power line communication) and EU project SPARTACUS (integration of further sensors).

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