SOC Needs for optimal active or passive Li-ion balancing techniques

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Abstract

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Integrated interleaved active balancing converter for battery management applications

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Abstract Accurate State Of Charge (SOC) estimations are one of the critical functionalities of Battery Management Systems.
(BMS), whether it is for single-cell batteries or multiple-cells batteries. However, battery- SOCs are usually generalized without any consideration about cell disparities. In this presentation, we propose to increase battery-SOC accuracy by analyzing the already existing studies about SOC estimation for single cell (cell-SOC) and some preliminary reflections in order to develop a battery-SOC which takes cell disparities into account. A focus is also done to explore how to link uncertainties of cells estimations and accuracy of the final battery-SOC in order to give reliable information to the user about the remaining charge amount. Moreover, this management at cell level can also be used to develop passive and/or active balancing strategies. The experimental resources used to benchmark the algorithms – high voltage battery with adapted power supplies, including BMS, current sensors and interfaces – are described afterwards.

Introduction

Series connected Li-ion batteries need robust BMS to ensure safety, maximum autonomy, accurate battery state estimations and the best ageing conditions for the battery. Among these functions, the state of charge, representing the coulomb amount stored in a cell, is one of the critical feature to meet this goal considering that it is intended to give a picture of the rate of charges stored in a cell and that many facets of cell management are usually described thanks to this indicator, including the cell balancing in series association battery stacks. However SOC values can only be estimated through indirect methods. Many papers list these SOC estimation methods [1] or detail particular algorithms using impedance spectroscopy [2], Kalman filters [1], neural networks [3], fuzzy logic [4], voltage measurements or coulomb counting. But these algorithms are usually developed considering that the battery behaviors are the same for single or multiple cell battery stacks. This assumption is invalid when the cells present disparities in their initial characteristics – like internal resistances or capacities – and especially under ageing conditions – like internal temperatures gradients. This paper aims to present the analysis of a cell-SOC algorithm and to design a battery-SOC which reflects the battery disparities to enable first an accurate charge estimate and second to optimize the balancing needs in battery stacks with cell disparities. The first section of this abstract briefly presents the elementary cell-SOC algorithm used for this work. In the second section, the development of cell oriented battery-SOC algorithm is progressively detailed. Finally, experimental validation process is examined in the last section.

Description of SOC algorithm at cell level

The basic definition of a SOC is the charge number that is stored in a cell over the maximum charge number Qmax that the cell is able to store when it is fully charged. Consequently, the relation used in coulomb counting methods and describing SOC variation comes below: where IC(t) is the cell current. It appears that precision of the current sensor is a key factor to have a reliable SOC estimation but no matter of the instantaneous accuracy, error margins will continue to increase with time due to sensor inherent static errors. Coulomb counting is not a robust stand-alone algorithm. Another usual way to estimate SOC value is to take advantage of the relationship between the open- circuit voltage VOC and the SOC. This method is especially useful for low power applications and battery chemistries with large d(SOC)/d(VOC): the first case limits uncertainties coming from internal voltage drop and the second case reduces the impact of voltage measurement inaccuracy on SOC estimation error. Otherwise, this method loses a part of its reliability but is sufficient to calibrate SOC estimation if the cell is at rest for a long period of time. In usual Li-ion battery (with characteristic curves as depicted on fig. 1), this technique can also be relevant for the estimation of the extreme SOC, where the slope is much higher than for medium SOC. Fig. 1: Experimental result describing between the VOC and the SOC for LiFePO4 chemistry. SOC algorithm In this section, the target is to estimate charges stored in a multiple-cells battery, whatever are the cells disparities and without any prevision about balancing compensations. Coming out of these estimations at cell level is expected charge level that can be made available to the user. In a first step, we consider a group of cells with the same capacities but with various SOC disparities. case study and its associated SOC estimation are described in figure 2 over a battery cycle current. Fig. 2: Case study illustration for SOC disparities. In this case, the SOC-battery has to show that ΔSOC1*Qmax of its total capacity is lost because disparities. Generalization for N cells gives where ΔSOCmax is the maximum SOC difference among cells. In the second step, aged cells are introduced. SOC estimations alone are no more predict which cells reach at first maximum or minimum charge levels. For this, it is necessary to switch from cell-SOC representation to cell charge number representation and to use cell state of health (SOH), defined as the current capacity of the cell (Qcell) compared to its initial maximum capacity 0 10 20 30 40 50 60 70 2.5 3 3.5 4 State Of Charge (%) Voltage (V) Open-circuit voltage of a LiFePO4 cell battery Fig. 1: Experimental result describing the relationship SOC for LiFePO4 chemistry. SOC algorithm In this section, the target is to estimate the number of cells battery, whatever and without any prevision coming out of these is expected to derive the charge level that can be made available to the user. , we consider a group of cells with the SOC disparities. The case study and its associated SOC estimation are bed in figure 2 over a battery cycle with 1C illustration for SOC disparities battery has to show that of its total capacity is lost because of Generalization for N cells gives eq. (1): is the maximum SOC difference cells are introduced. Cell- SOC estimations alone are no more sufficient to reach at first maximum or . For this, it is necessary to SOC representation to cell charge number representation and to use cell state of health current capacity of the cell s initial maximum capacity Qmax: Effective capacity of a battery with series cells can now be estimated through remaining charge number of the cell and the cell Y limiting discharge: Using (2) in the previous equation, equation (3): In the end, we define the equation (4): Another aspect to make explicit is the link between cell-SOC uncertainties uncertainties. For example, in the situation described in figure 3, equation (3) and ensure a robust battery-SOC: This formulation ensures the user that h least SOCbat * Qmax_bat. In compensation of robustness, the effective battery capacity decreased by the sum of SOC1_up – SOC2_bot. Fig. 3: Example of cell-SOC uncertainties impact In addition to contribute to improve b accuracy, management of the batteries at cell allows more adaptive balancing strategies example, user can decide to adjust of some cells in order to increase available power to control ageing conditions of the 70 80 90 100 of a LiFePO4 cell battery (2) Effective capacity of a battery with series-connected cells can now be estimated through Qmax and the the cell X limiting charge limiting discharge: equation, we obtain the battery-SOC through to make explicit is the link between and battery-SOC For example, in the situation described and (4) can be adapted to user that he can get at In compensation of this robustness, the effective battery capacity is the sum of...
uncertainties $Q_{\text{max}}$ to improve battery-SOC, management of the batteries at cell level by balancing strategies. For adjust the average SOC $r$ to increase available power or g conditions of the cells with low SOH. Validation protocol The development of SOC algorithms is supported with both the model – based on experiment. Our test bench is composed of 48 LiFePO4 cells connected in series with passive BMS, whose balancing and SOC algorithms can be upgraded. An electronic load and a power allow to cycling the battery up to 5kW during charges and 7.2kW during discharges and can be remote controlled through an interface developed with Labview software. Fig. 4: Illustrations of experimental cycling Validation protocol is based on reference cycles allowing to benchmark features of SOC algorithms. The validation protocol used on this analysis in figure 5 but it may differ as a function of the desired element to be characterized and the application used to compare accuracy features of cell battery-SOC described above with the ones of standard battery-SOC algorithms. Fig. 5: Current reference Phase A is used to allow potential calibrations in order to have accurate estimations at the beginning of The development of SOC algorithms is supported based on [5] – and the is composed of 48 100Ah cells connected in series with passive BMS, algorithms can be upgraded. An electronic load and a power supply allow to cycling the battery up to 5kW during charges and 7.2kW during discharges and can be remote interface developed with : Illustrations of experimental cycling bench Validation protocol is based on reference cycles allowing to benchmark features of SOC algorithms. used on this analysis is given as a function of the desired characterized and the application. It is used to compare accuracy features of cell-SOC and SOC described above with the ones of nce cycle allow potential calibrations in order to have accurate estimations at the beginning of phase B. In this phase, the ability to keep small uncertainties is tested through different cycling current levels and rest periods. During phase C, extern interventions provoke which allow observing algorithms resilience. Conclusions This paper focused on SOC algorithms for battery with multiple cells connected in series. In a first part, two basic methods – coulomb counting and cell voltage measures – were used together to compensate each other uncertainties. The second part detailed in a few steps how to SOC estimator representative of the state of each cell and their disparities. A development was also proposed to reflect accuracy of cell SOC one. Moreover, this paper on more adaptive passive and active strategies. In the last part, the test bench and benchmarking cycle used to validate algorithms described. References 1 G. Plett, “Extended Kalman filtering for battery management systems of LiPB packs. Part 2: Modeling Power Sources 134 (2), 2004 2 S. Rodrigues et al, “AC impedance and state charge analysis of a sealed lithium rechargeable battery”, J Solid State Electrochem (1999) 3: 397-405 3 M. Charkhgard et al, State for Lithium-Ion Batteries Using Neural Networks and EKF, “State-of-Charge Estimation for Lithium Ion Batteries Using Neural Networks and EKF, Industrial Electronics, IEEE Transactions December 2010, vol.57, no.12, pp.4178,4187 4 Alvin J Salkind, et al, “Determination of state charge and state-of-health of batteries by fuzzy logic methodology”, Journal of Power Sources, July 1999, Volume 80, Issues 1 5 M. Urbain, “Modélisation électrique et énergétique des accumulateurs Lithium ligne du SOC et SOH”, thesis, 2009 phase B. In this phase, the ability to keep small uncertainties is tested through different cycling current levels and rest periods. During phase C, provoke voluntary disparities algorithms resilience. SOC algorithms for batteries with multiple cells connected in series. In a first part, coulomb counting and cell were used together to compensate each other uncertainties. The second part detailed in a few steps how to develop a battery- representative of the state of each cell A development was also proposed to reflect accuracy of cell-SOC on battery- his paper opens perspectives passive and active balancing In the last part, the test bench and benchmarking cycle used to validate algorithms were Extended Kalman filtering for battery management systems of LiPB-based HEV battery and identification”, J. 2004, 262–276. AC impedance and state-of- a sealed lithium-ion J Solid State Electrochem State-of-Charge Estimation Using Neural Networks Charge Estimation for Lithium- Ion Batteries Using Neural Networks and EKF,” Industrial Electronics, IEEE Transactions, I.57, no.12, pp.4178,4187 Determination of state-of- ealth of batteries by fuzzy , Journal of Power Sources, Volume 80, Issues 1–2, Pages 293-300 Modélisation électrique et énergétique des accumulateurs Lithium-Ion. Estimation en thesis, 2009

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