Simultaneous EIS Measurements on Several Single Cells in High Current Battery Stacks Involving Time-Drift Removal by Z-HIT

Lithium-ion batteries become more and more popular because they show important advantages over competing technologies. Particularly, the high energy density is a key advantage for the technical application in battery plants. However, the stacking of single-cells in order to obtain a higher voltage is accompanied by several difficulties.
Simultaneous EIS measurements on a battery-stack under discharging conditions show that the cells behave as "individuals". Moreover, under these conditions the cells exhibit a small but remarkable drift at low frequencies which has to be detected and considered in the validation process.

Typically, the voltage of a single battery is in the range of one to four volts, for instance a $LiFePO_4$ battery provides an open circuit voltage of about 3.3 volts. This voltage and power is by far too low for most technical applications. Same as with fuel cells, a number of cells must be stacked to achieve a higher power.

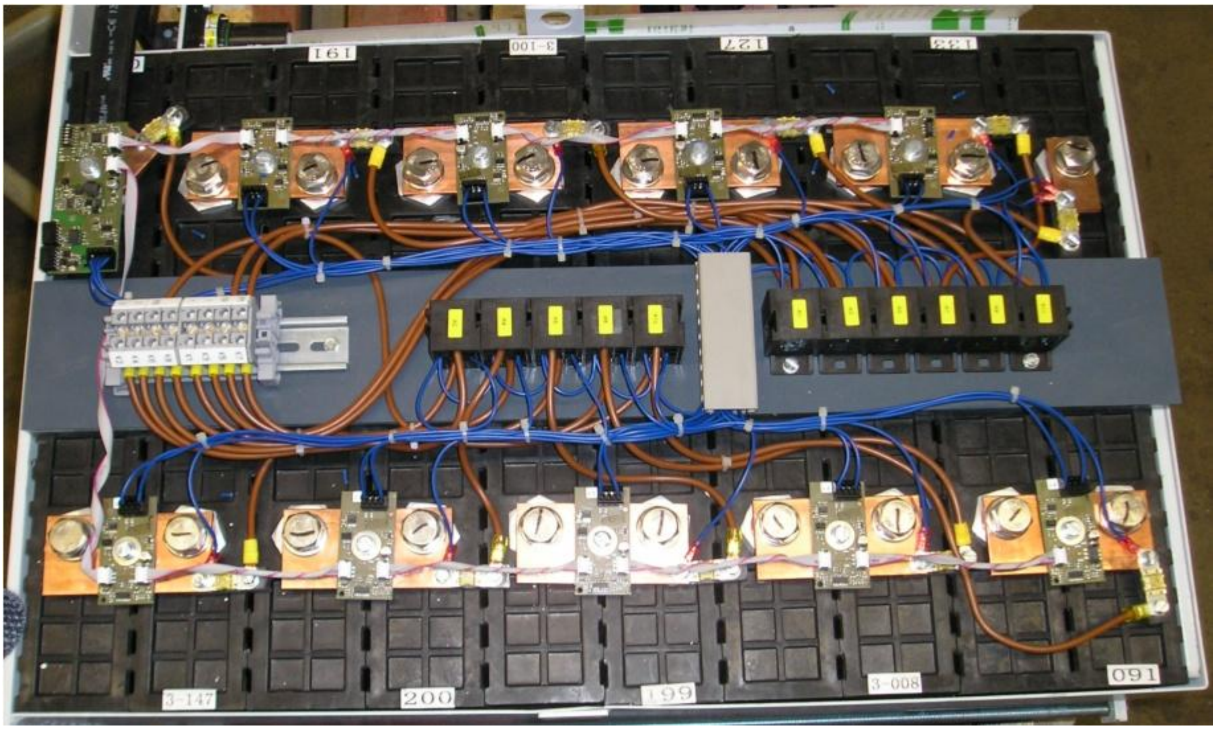

figure 1: Cluster of $LiFePO_4$ cells including monitoring- and balancing circuitry (with kind permission of R. Gross, BNO-consult, 97337 Dettelbach, Germany)

A typical arrangement of batteries within a commercially available stack-cluster is depicted in figure 1. In this “cluster”, ten $LiPO_4$-cells are series-connected. Besides the cells, additional components like balancing units as well as electromechanical switches are shown. Please note that for the construction of the complete stack, several clusters depicted in figure 1 are connected in serial to achieve the required DC-voltage of the stack, constructing the complete energy storage system.
It is safe to assume that individual cells within the stack do not behave identical regarding power, charge balance and stability. Performance loss of individual cells limits the overall performance of the stack. In order to identify such differences, dynamic investigations of individual cells within a battery

stack during operation are favorable. For this purpose, Electrochemical Impedance Spectroscopy (EIS) has been established as a powerful tool for the mechanistic interpretation of the involved processes.
Migrating impedance measurement techniques from laboratory to application scale is a challenging task. Besides the capability to handle the high power of the stack safely, the acquisition of the individual cells within the stack must be performed synchronously in parallel to avoid time delays between the EIS data sets of the different stack elements.
For these purposes, Zahner has developed two hardware components which are especially designed to operate in combination perfectly. The first component is the EL1000 (details here), an external electronic load which can be controlled by an IM6/Zennium like all other external Zahner add-ons – for instance the potentiostats of the PP-series. The second component is the PAD4 (details here) card(s), which allows to measure EIS-scans on individual cells of a stack simultaneously, e.g. true in parallel.
Both components enable the handling of stacks/clusters in the range of ± 100 volts DC, whereas the PAD4 unit enables the EIS measurement of single cells of ± 4 volts AC (standard) within the stack. An additional, notable feature of an EL1000-setup is that its maximal power can be expanded by adding an external third party device like an additional electronic load or an electronic power supply.

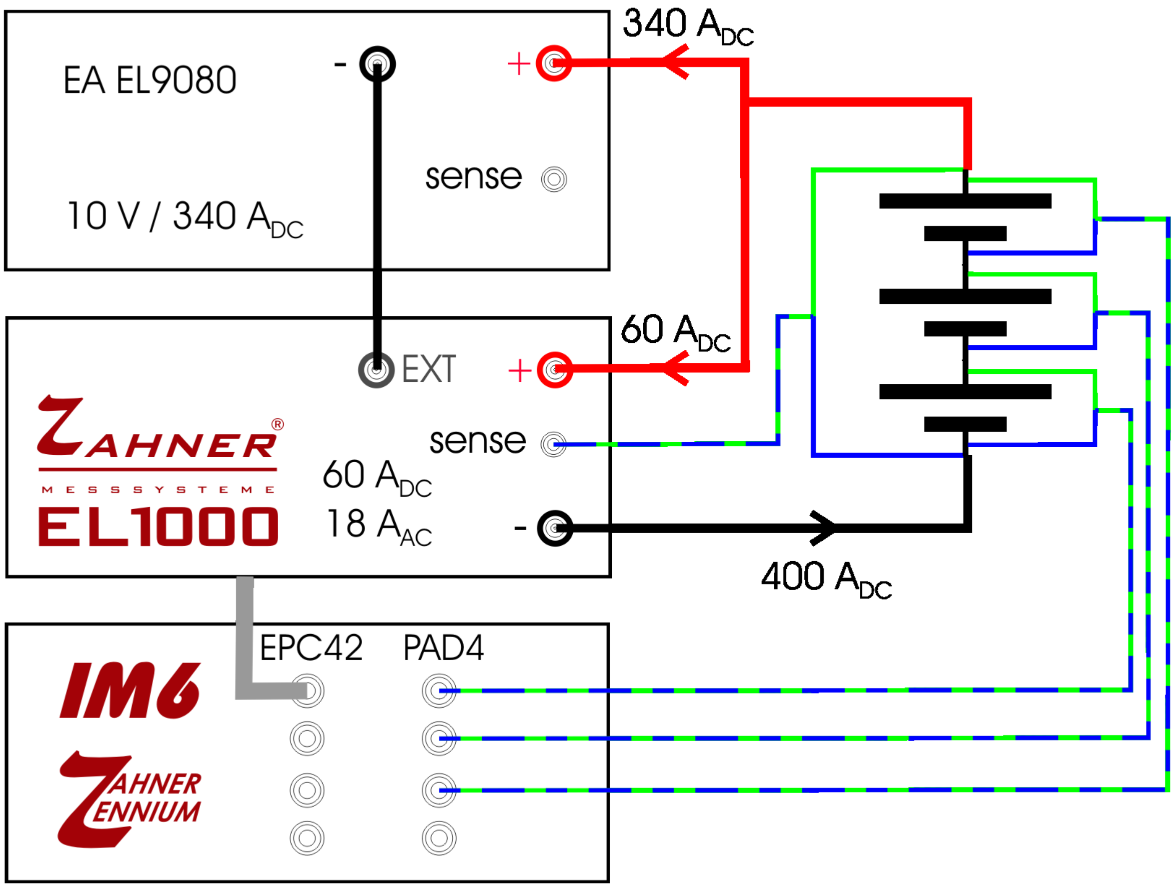

figure 2: Scheme of a typical stack measurement. The 400 A total stack-current is split up in 340 A DC sunk by a third party electronic load and 60 A DC bias superimposed by 18 A AC amplitude by the EL1000; in parallel, single cell impedances were recorded in real time using the PAD4 channels (current leading wires: red/black, voltage sensing wires: green/blue)

A typical arrangement for measuring clusters and/or stacks is depicted in figure 2. In this example, an arrangement of 3 $LiFePO_4$-cells with a capacity of 400 Ah each cell were series-connected. The impedance measurements were performed using a DC-bias current of 400 A. Since in stand-alone mode the EL1000 is able to handle “only” 200 A, an additional load (EL 9080) was added to enhance the current capabilities. The total amount of the 400 A DC- current was split up as indicated in the figure caption. Impedance measurements are performed galvanostatically, using an AC-amplitude of 18 A, whereby the individual cells are measured using a PAD4 card.

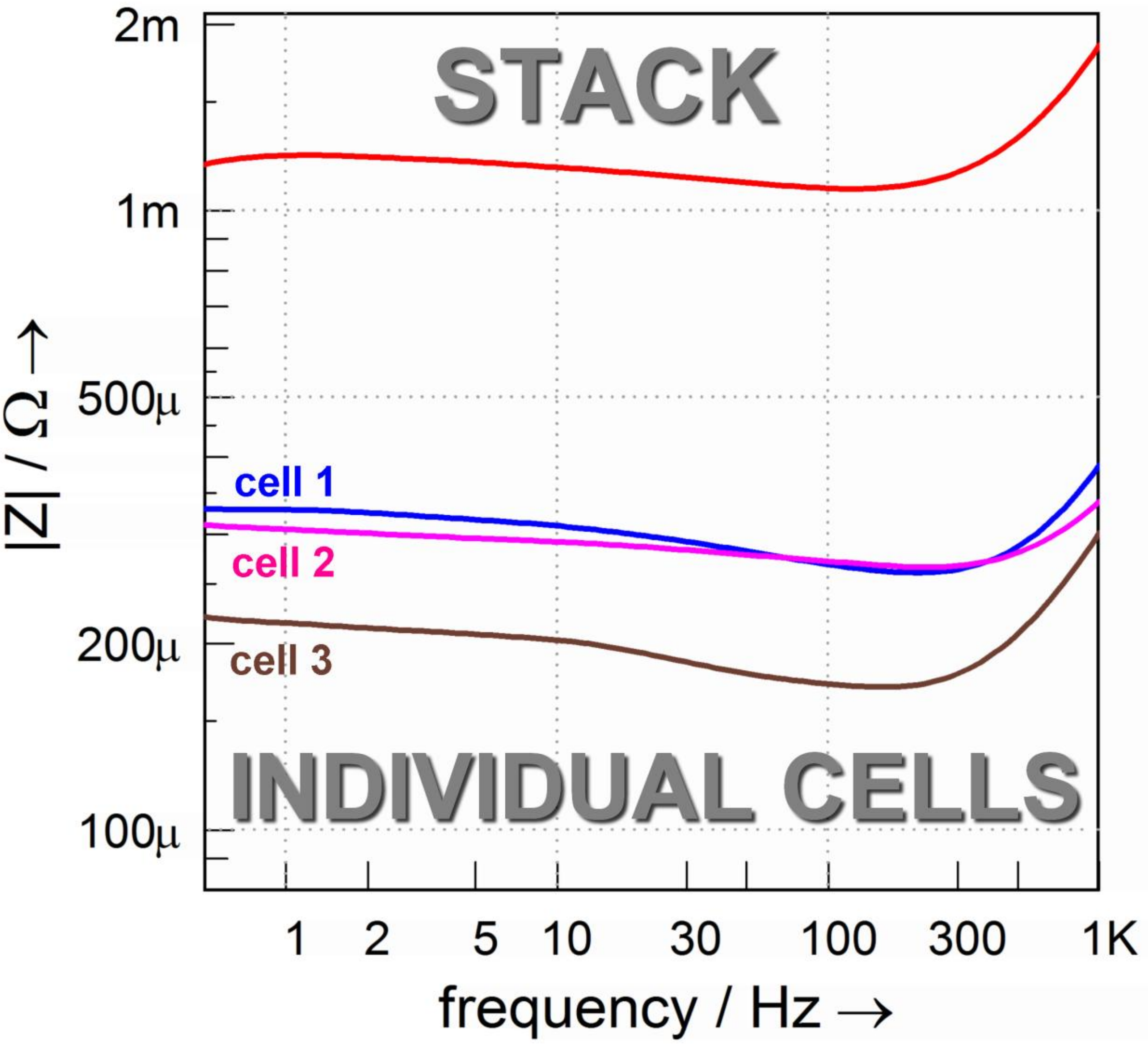

figure 3: Impedance spectrum of a short-stack measurement at 400 A DC-current, complete stack (top) and individual cells (bottom) using the combination EL1000/PAD4. For clarity, the phase shift is omitted.

In figure 3 the result of the impedance measurements on the short-stack depicted schematically in figure 2, omitting the course of the phase angle for clarity. The impedances of the single cells sum up to the impedance of the stack but the individual cells behave different. This can be clearly seen due to the true parallel measurement technique using the PAD4.

In addition, the performance of the individual stack elements under high load were analyzed and weak cells could be identified. As expected, the current flowing during the measurement time causes a time drift of the EIS data due to the changing state of the cells. This problem was detected by means of the Z-HIT algorithm. Z-HIT was then used to eliminate the corresponding spectral errors by providing virtually time-independent EIS data sets.