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Battery accelerated testing for second-life Li-ion cells

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Within the BAT4SEL project, CSEM verified the validity of an accelerated testing procedure to estimate the State of Health (SoH) of second-life Li- ion cells (i.e. used Li-ion cells) with no prior knowledge of their use cases. The project objective was to give a statistical quantification of the trade-off between the SoH estimation precision and the required testing time to obtain this estimation; for this reason, a statistically representative number of samples from e-bike applications has been provided to CSEM from project partner Libattion GmbH. The testing analysis was based on four selected technologies of cathode chemistries (NMC and NCA). Three types of indicators have been applied (resistance-based, efficiency-based and EIS- based indicators) at different testing conditions. The results obtained were promising and several routes of exploitations are under investigation.

Second-life applications of Li-ion cells will allow for a more sustainable battery value chain. After the first-life application, specific procedures that qualify the residual energetic value of the cell and/or module are needed. Such procedures should be fast enough not to create high additional cost for the second- life reporpusing entity. CSEM developed different fast testing procedures to find suitable proxies which can satisfy the two following KPIs: affordable testing time per cell and acceptable SoH estimation error (mean error and standard deviation). The whole testing campaign was based on 523 cylindrical cells (18650 format, Figure 1) of four selected technologies: LG Chem MJ1 (NMC, type A), Sony VC7 (NCA, type B), Sanyo Panasonic GA (NCA, type C), and Sony NC1 (NMC, type D).

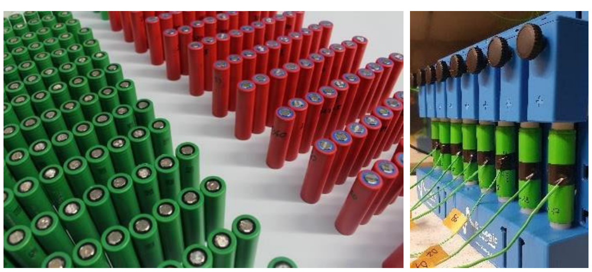

Figure 1: Figure 1: used Li-ion cells (left); cells under test (right).

Procedure and methodology

The testing methodology has been based on two different sub-sets of tests: (i) diagnostic tests, where a representative sample of cells have been characterized to find existing correlations between developed proxies and SoH and (ii) validation tests, where a large number of samples have been tested to validate the protocols by comparison of the estimated and measured SoH values. Diagnostic and validation protocols were obtained by combining different testing phases (Figure 2):

- Phase A: resistance, efficiency and EIS measurements at random voltage (i.e. the voltage at which the cell has been received).
- Phase B: full cycle for capacity/SoH measurement.
- Phase C: same as Phase A, but at fixed voltage of 3.6V.

Three main type of indicators have been applied: resistance- based indicators (R-based), efficiency-based indicators (EE- based) and EIS(impedance)-based indicators. Moreover, the correlation assessment has been verified for three different testing conditions: (i) random voltage condition (i.e. testing samples at different SoC, as received); (ii) nominal voltage condition (i.e. testing samples at same SoC) and (iii) random voltage post-triage (i.e. after filtering out the cells which were outside a specific SoC interval).

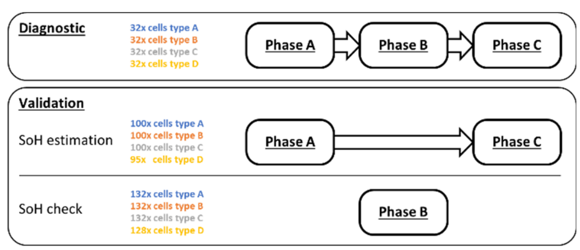

Figure 2: Combination of testing phases for diagnostic and validation.

Diagnostic and validation tests results

The results of diagnostic tests showed that each proxy has its own advantage and that experiments at random SoC rarely provide a satisfactory correlation, it is hence better to discard overcharged or over-discharged cells. This was also confirmed by the validation tests where such filtering triage improved the SoH estimation of almost 20% while reducing its standard deviation.

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As regards the indicators, R-based indicators provided an average estimation error below 2.5%, efficiency- based indicators provided a stable estimation error around 2%, while EIS (impedance)-based indicators showed slightly higher estimation errors around 3% but lower standard deviation.

Remarks and outlook

Overall, the BAT4SEL project confirmed the validity of the accelerated testing approach developed by CSEM with the following remarks:

- A pre-triage process is a good practice before qualifying second-life cells.
- The characterization process takes 1 month per technology.
- Precision and accuracy of the testing equipment will influence the results.
- There is not the best proxy for all the different technologies. User should choose according to his/her needs regarding accuracy, robustness, available testing time, or testing machine applicability.
- Results are technology dependent, and no guarantee can be made that the investigated results will provide positive results for all technologies, adaptations might be required.

The main exploitation routes for the BAT4SEL estimation algorithm are the following: (i) to implement it into existing testing machine; (ii) to verify its applicability also at battery module level; (iii) to implement it into current or future BMSs for second-life applications.

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