Understanding aging characteristics of a stationary lithium-ion battery: Single-cell tests, system operation, and model-based interpretation

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Lithium-ion batteries are the most dominant electrical storage system for both residential and commercial stationary storage systems for renewable energy storage [1]. Compared to portable applications such as consumer electronics or electromobility, stationary storage systems take economic advantage of the possibility of using bulky and large-format cells that are not challenged by rigorous weight reduction requirements. Still, the lifetime of batteries is vital for a stationary storage system [2].

We present a combined experimental and modeling study of the aging characteristics of large-format (180 Ah) lithium iron phosphate/graphite (LFP/G) cells. A total of 28 cells were experimentally investigated in three main test groups over a duration of approx. two years. In a cyclic aging group, cells were continuously cycled without rest at 35° C and 50 °C. In a calendaric aging group, cells were kept at constant voltage corresponding to 100% SOC and 60% SOC at 35 °C and 50 °C. In parallel, 16 cells were operated within a commercial 9.2 kWh battery system that underwent continuous cycling with different protocols. Periodical checkups revealed that regardless of experiment type all cells at 35 °C outperformed the ones at 50 °C in terms of capacity retention (cf. Figure). On the other hand, the SOC of the calendric aging cells show no distinctive pattern. The average capacity retention of cells integrated into the commercial storage system was 88 %, which is in the range of the single-cell results despite the lower temperature of the system. The combined results allow the deconvolution of cyclic and calendaric aging effects as well as the influence of temperature.

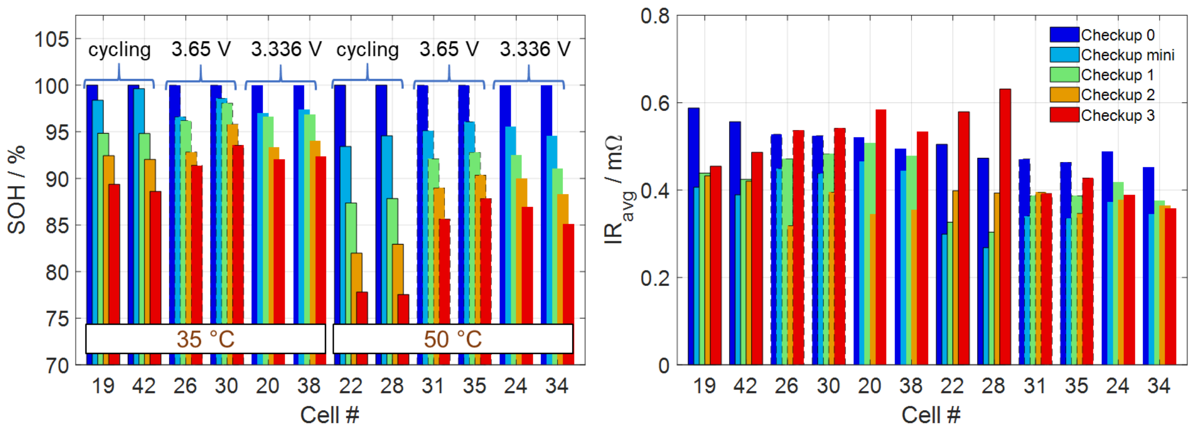

Figure: Experimental aging characteristics of 180 Ah large-format LFP/graphite single cells as function of time and aging protocol (Checkup 0: initial performance; checkup 3: performance after approx. two years of operation). Left: State of health (capacity retention); right: internal resistance.

In parallel, physicochemical models were developed that describe capacity loss due to formation of solid electrolyte interphase (SEI). Here, combined calendaric and cyclic aging are described on a microscopic basis by coupling an electrochemical SEI formation model with a mechanical model of SEI rupture. Key parameters of the model are determined by comparing simulation results to the experimental aging characteristics. The model predicts an initial nonlinear capacity loss, followed by a linear capacity loss as function of time. This is consistent with experimental observations.

Our investigation presents for the first time a detailed comparison of aging factors of large-format (180 Ah) commercial LFP cells up to 1500 full cycles. The study as well provides quantitative aging properties of individual cells, which can be useful for both researchers and manufacturers.

[1] K.-P. Kairies, J. Figgener, D. Haberschusz, O. Wessels, B. Tepe, D. U. Sauer, Journal of Energy Storage 2019, 23, 416–424.

[2] M. C. Yagci, T. Feldmann, E. Bollin, M. Schmidt, W. G. Bessler 2021 (submitted to Journal of Energy Storage).