Incremental Capacity Analysis (ICA) as a diagnostic tool for the State of Health (SoH) estimation of 2nd Life Batteries

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Field of Study: Renewable Energies

The results of the study have shown that an application of the ICA method on aged batteries is possible. Accurate results could be obtained with a deviation less than 5 %. In particular, the feature "peak location" (see green arrow in Figure 3) gave a promising result. Nonetheless, only a partial charging curve (from 2.2 to 2.4 V) was applied, as indicated in Figure 2 and 3.

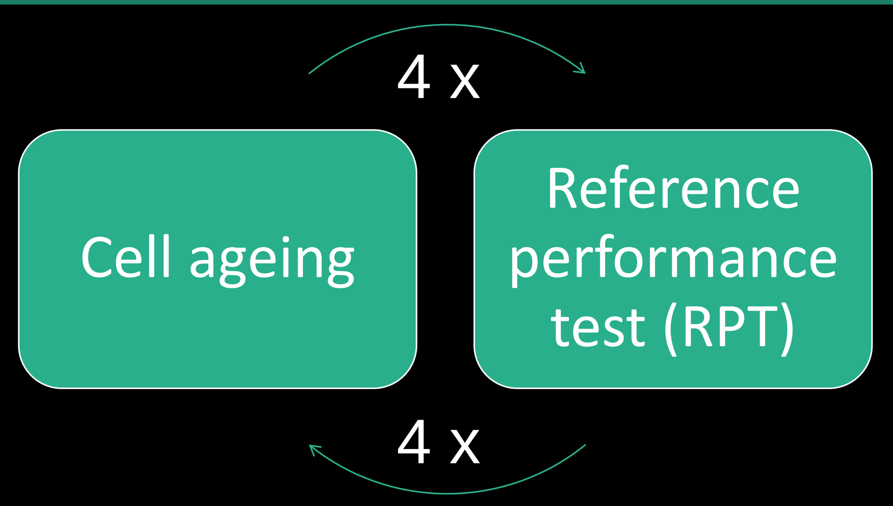


Figure 1 Experimental study - the procedure was repeated four times.

Experimental Study: In order to answer the research questions, the proposed ICA method was tested with two previously aged battery cells. In the beginning, a reference performance test (RPT) was performed to define the (remaining) capacity of the battery cells. This procedure includes the complete discharge and charge of the battery, which allows to determine the capacity of the cell by the Coulomb counting method. The RPT procedure was conducted with the constant current (CC) and constant voltage (CV) procedure. After the RPT, the battery was aged with a predefined load cycle. The whole procedure is repeated four times, as indicated in Figure 1. The cells were tested at 25°C but aged at 50°C, in order to age them faster.

The ICA method: Figure 2 visualizes the procedure of creating the ICA curve. The constant charging current a) and the charging voltage b) are used to create an ICA curve. The charging current curve is integrated by the time. This leads to the capacity curve presented in c). The capacity curve c) is then plotted against the voltage curve b), which results in the curve d). Thereafter, this curve is derived by the voltage, which then represents the characteristic ICA curve, as presented in e). As soon as the ICA curve is created, the three feature values "location", "amplitude" and "area" are extracted on a partial voltage interval (from 2.2 to 2.4 V), as visualized in Figure 3. This procedure is repeated for all RPTs (5 times). Each feature value is set in reference to the remaining capacity with a linear regression analysis, which is presented in Figure 4. This resulted in a linear model, which was validated with the historical data of the used cells. In order to compare the models, the estimation error was calculated.

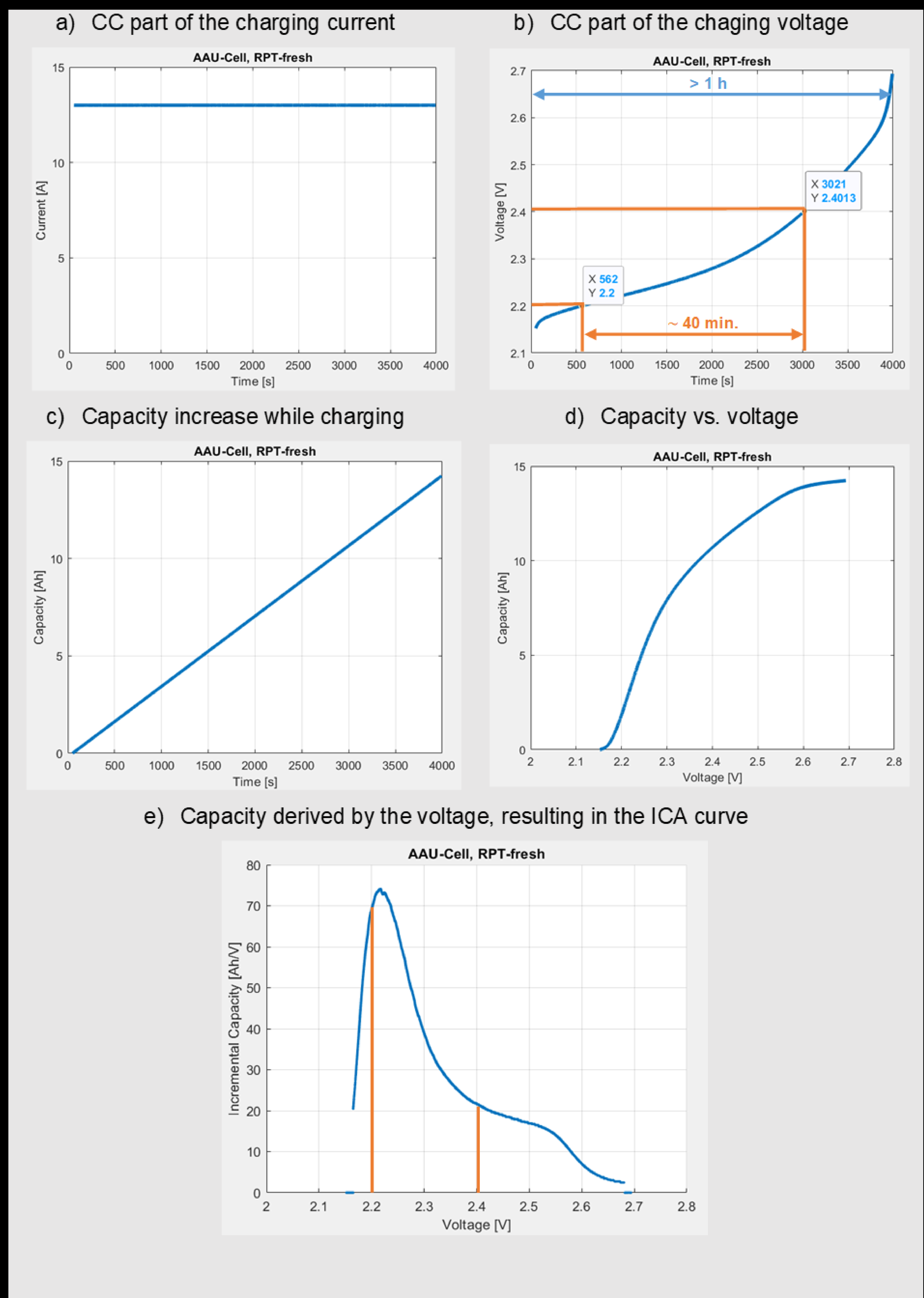


Figure 2 Demonstrative incremental capacity analysis (ICA) procedure with an LTO/LNMC cell, where a) shows the CC charging current, b) the CC charging voltage, c) the capacity increase, d) the capacity vs. voltage and e) the capacity derived by the voltage, resulting in the ICA curve. The orange lines indicate the voltage level in the range between 2.2 and 2.4 V. The blue arrow indicates the time to measure the whole charging curve in order to create the ICA curve. The blue arrow indicates the time needed for a partial charging.

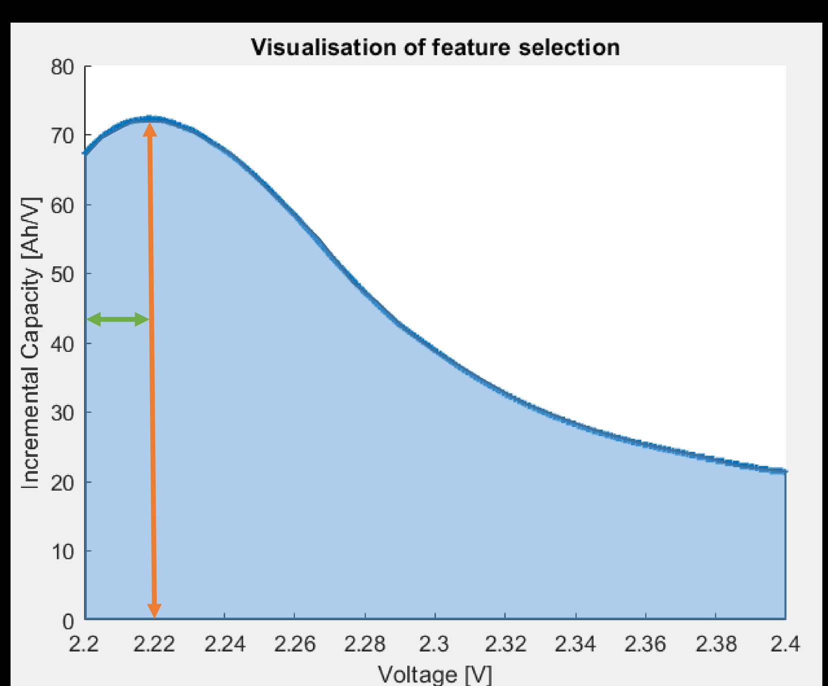
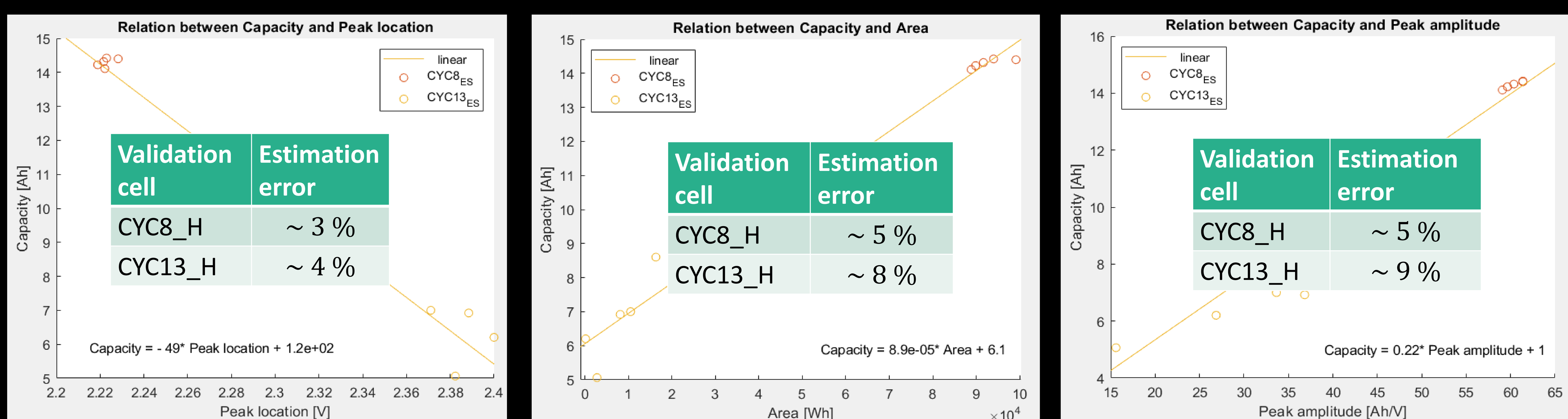


Figure 3 A partial ICA curve on an example of an LTO/LNMC cell, where the voltage interval between 2.2 and 2.4 V is chosen. The area [Ah] is indicated in blue; the peak amplitude [Ah/V] is indicated with the orange arrow and the peak location [V] is indicated with the green arrow.



Validation cell	Estimation error
CYC8_H	~ 3 %
CYC13_H	~ 4 %

Validation cell	Estimation error
CYC8_H	~ 5 %
CYC13_H	~ 8 %

Validation cell	Estimation error
CYC8_H	~ 5 %
CYC13_H	~ 9 %

Figure 4 Three models based on the different feature values "location", "amplitude" and "area". For this battery chemistry 80% remaining capacity lies at 10.7 Ah. The feature "location" achieved an an average estimation error of ~3% for values above 80% remaining capacity and an average estimation error of ~4% for values below 80% remaining capacity. The feature "area" achieved ~5% for above 80% and an ~8% for below. The feature "amplitude" achieved ~5% and ~9% respectively.