EVERLASTING

Electric Vehicle Enhanced Range, Lifetime And Safety Through INGenious battery management

D8.8 – White Paper 05

August 2018

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DISCLAIMER

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LIST OF ABBREVIATIONS AND ACRONYMS

ACRONYM	DEFINITION
DC	Direct Current
DST	Dynamic Stress Test
EV	Electric Vehicle
SOC	State Of Charge
SOH	State Of Health
DOD	Depth Of Discharge
EOL	End-Of-Life

1 WHITE PAPER: INTRODUCTION

The EVERLASTING project (http://everlasting-project.eu/) will develop innovative technologies to improve the reliability, lifetime and safety of Lithium-ion batteries by developing more accurate, and standardized, battery monitoring and management systems. This allows predicting the battery behavior in all circumstances and over its full lifetime and enables pro-active and effective management of the batteries. This leads to more reliability and safety by preventing issues rather than mitigating them.

To raise the awareness of the vital and positive role of battery management systems (BMS), a three-monthly white paper will be written on different BMS topics, aimed at a general technical public. These white papers are a few pages long and will be distributed via the EVERLASTING website and through the partners.

The first white papers focused on “BMS Functions” and on the “State of Charge (SOC) definition” and “Evaluation of SOC accuracy”. The next 2 white papers focused on “State of Health (SOH) definition” and “Cell testing and the estimation of SOH”.

2 WHITE PAPER 05: CELL TESTING AND THE ESTIMATION OF SOH

In this white paper we will discuss SoH estimation and the information gained through cell testing. We start from the definition of SoH, elaborate on the types of ageing and the cell tests that are performed within EVERLASTING. Finally, we discuss SOH algorithms and the need for SOH prediction.

2.1 INTRODUCTION

In the previous white paper, two different aspects of battery cell ageing were highlighted; the increase of internal resistance and loss of capacity.

- A loss of **capacity** is the most commonly used metric for SOH assessment. It is expressed as the actual capacity of the battery (Q_{actual}) versus the value when the battery or cell was new (Q_{initial}).

$$SOH_{cap,1} = \frac{Q_{\text{actual}}}{Q_{\text{initial}}} \qquad (1)$$

- An increase in **internal resistance** will decrease the cell’s ability to deliver (peak) power. Consequently the SOH can be expressed in relation to the internal resistance value when the cell was new:

$$SOH_{Ri,1} = \frac{R_{\text{i,initial}}}{R_{\text{i,actual}}} \qquad (2)$$

Usually, a cell or battery is considered EOL when its internal resistance has doubled [1], corresponding to $SOH_{Ri,1} = 50\%$ in equation 2, or when the remaining energy capacity has fallen below 80% in (1). In practice, it is usually observed that EOL due to capacity loss is reached before doubling of the internal resistance. The underlying causes for ageing mechanisms are the subject of extensive research and depend strongly on the composition of the electrodes, the type of separator and electrolyte, ...

2.2 DEGRADATION AND CELL TESTING

Degradation of a cell can usually be classified [2] as either calendar ageing or cyclic ageing. Calendar ageing is related to the consequences of cell storage while cyclic ageing is associated with the (cyclic) utilization of a battery. Through extensive cell testing, the influence of the different factors and environments on the degradation rate can be identified.

Battery technology researchers design different battery cycle life test profiles as a result of different research objectives. In the EVERLASTING project, cells are aged under various controlled circumstances and using different profiles.

2.2.1 CYCLIC AGEING TESTS

Cyclic ageing tests usually are ‘synthetic profiles’ that consist of charge and discharge cycles at a constant rate and within predefined limits (upper and lower voltages or SOC levels). The actual battery capacity is measured during regular **check-up tests**. The total ‘absorbed’ and ‘released’ charge during this capacity check-up test is recorded and plotted versus throughput or time. The checkup tests also include a series of controlled current pulses, that allow the determination of DC internal resistance.

An example of the cell voltage profile during a checkup test is shown in Figure 1. First are a few conditioning cycles (blue), followed by a DST profile (green) with dynamic discharge pulses. Then the capacity is measured by charging and discharging the cell completely at different C-rates (red) and eventually a sequence of pulsed charging and discharging. Care should be taken to limit the influence of the checkup tests on the ageing process. Therefore checkup tests should not be carried out too often.

The cycling tests are performed at different temperatures, since the ageing behavior can vary significantly at different temperatures. Within the EVERLASTING tests, temperatures vary between 0 and 45 degrees Celsius. Special climate chambers are used, to ensure a stable testing environment.

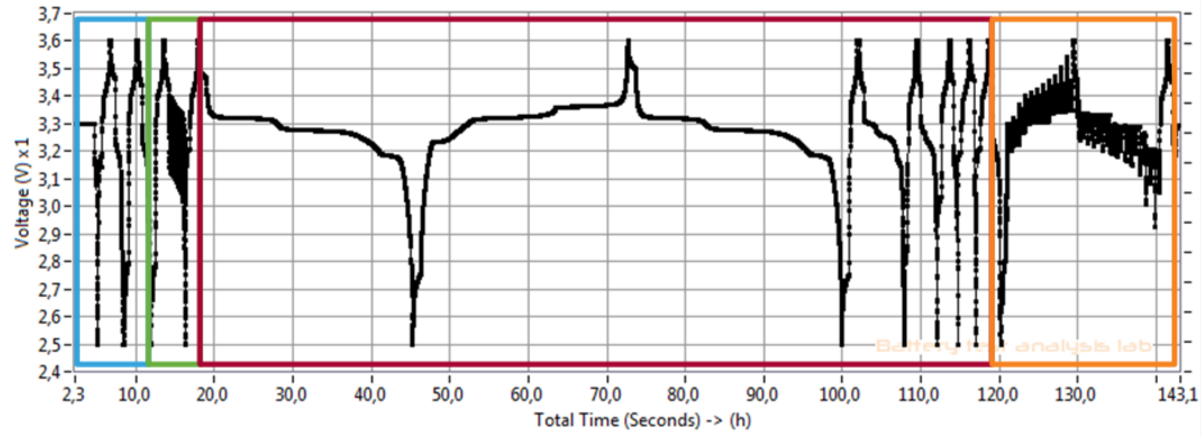

Figure 1: Example of a cell’s voltage during an extended check-up test: conditioning cycles, DST profile, capacity determination cycles and charge-discharge pulses.

2.2.2 CALENDAR AGEING TESTS

Cells also degrade with time, independent of the usage pattern. This is commonly referred to as calendar ageing. Temperature and storage SOC are known to influence this degradation. Within EVERLASTING, calendar ageing tests are performed at SOC levels of 10, 70 and 90% and at temperatures between 0 and 45 degrees Celsius.

Check-up tests are performed periodically to establish the ageing degradation, similarly as during cyclic ageing tests.

2.2.3 DYNAMIC AGEING TESTS

In addition to the synthetic tests, a real driving profile from an EV has been rescaled and is applied to a set of cells. Simulated driving continues until a pre-programmed SOC level is reached, after which the cell is charged again.

Eventually, checkup tests result in multiple values for the capacity and resistance, depending on the C-rate, SOC and cell history, illustrating the difficulty in finding a suitable reference for the SOH.

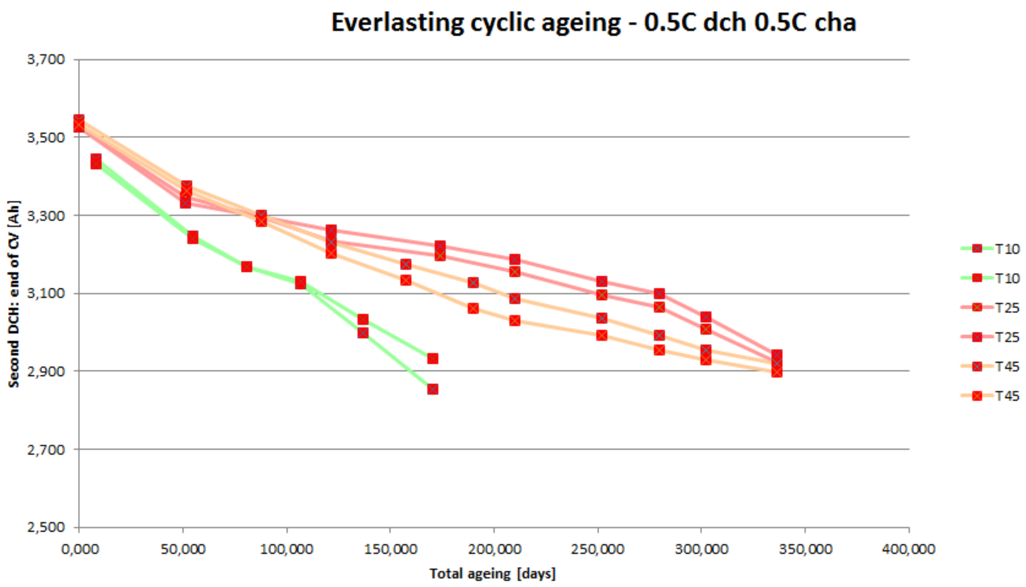

Figure 2: Example of cyclic ageing progress within EVERLASTING, showing the measured capacity during the checkup tests in Ah.

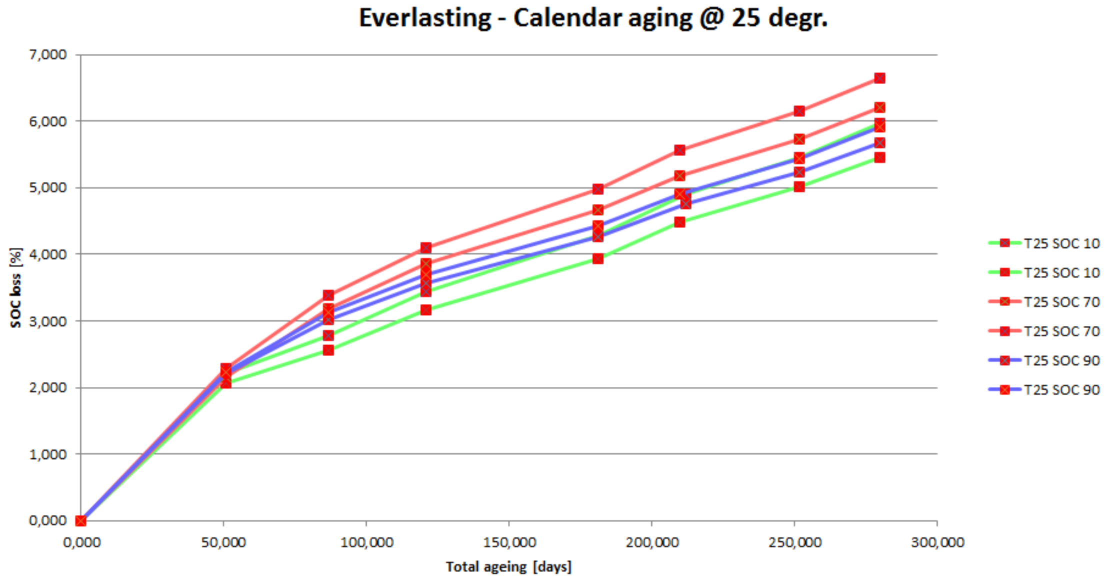

Figure 3: Example of calendar ageing progress within EVERLASTING, showing the loss in capacity in % of the original.

2.2.4 AGEING TESTS OBSERVATIONS

From the battery tests, a number of general observations can be drawn:

- Higher temperatures accelerate the ageing effects in both cycling and calendar ageing tests
- Charging and discharging over a wide Depth-of-Discharge (DOD) leads to faster degradation
- Higher currents will increase the ageing process rate
- Keeping cells at higher SOCs results in increased calendar ageing

Despite the large amount of tests, translating these observations into SOH figures and forecasts is not straightforward.

2.3 SOH ESTIMATION

2.3.1 APPROACHES

Various methods can be used to estimate the battery aging level [3][4]. In the previous white paper, the *direct approach* was described. This is mainly relevant when determining internal resistance or impedance, and needs an accurate method to apply current pulses or waveforms. As mentioned, the complexity and cost of the necessary hardware is prohibitive for production systems. Additionally the measurement can usually not be done online/during operation. Within EVERLASTING, work is being done to add impedance spectroscopy capabilities to battery management systems using the balancing circuitry.

Another type of algorithms are *measurement based models*. Typically, measurements are collected during cell tests (offline) and stored inside a model or map. Inside an application, actual measurement data is compared or correlated to the model to derive an estimate of the ageing, relative to the baseline established during the offline tests.

Adaptive models, such as those based on Kalman filtering, are also regularly used in literature, as they are the most flexible to deploy in situ. The drawback is a higher computational complexity.

2.3.2 OBSTACLES

One of the major issues of any SOH estimation method is to reach high accurate results. In [4], the accuracy of various approaches is compared, and found to average 95%. However, it is not mentioned how this accuracy was exactly benchmarked.

In previous EVERLASTING white-papers, it was discussed how the capacity of a battery cell can be measured, and that there is no single generally applicable value for its capacity. The energy content depends on the used discharge current, temperature and allowed operating window (the cell's voltage range). A typical condition is the use of a C/5 discharge rate at 25 degrees, and using a constant-current discharge. Therefore, online capacity estimation mechanisms are faced with the challenge of having to return a value that can be related to the datasheet values, even when the cell is not used under the same, usually synthetic, test conditions.

2.4 SOH EVOLUTION AND PREDICTION

Due to manufacturing variability and tolerances, cells exhibit slightly different capacities and internal resistances even when new. As long as these differences are small, the ageing process of the cells in a battery pack will be similar and in most cases evolve in 2 distinct steps. After an initial settling, the SOH will appear to degrade effectively linear with time and number of cycles, followed by a 'bending point', where a significant drop in SOH takes place. For good quality cells, this point should lie beyond the EOL (80% SOH_{cap}) of the cell.

In practice however, despite careful dimensioning during the design, it can happen that an EOL is reached more quickly. This is illustrated in Figure 4, where the SOH as capacity % from new over their life is shown. In the beginning, the capacities of Cell1 and Cell2 degrade almost identically, but after some time a quick and sudden deviation occurs. This makes Cell1 reach its EOL much sooner than Cell2.

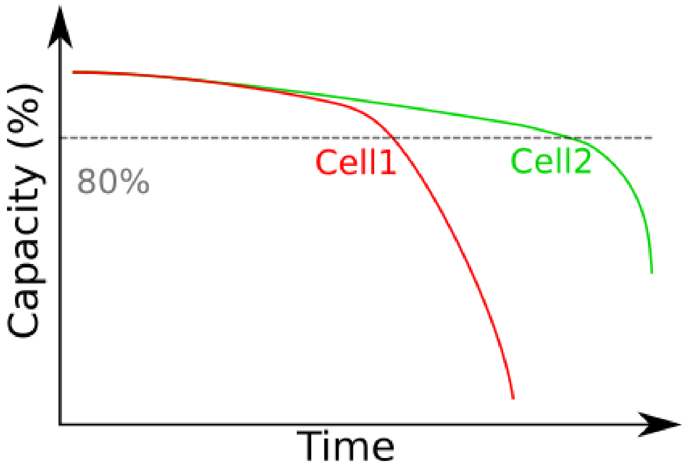

Figure 4: Different ageing of 2 cells / batteries and (early) EOL point

In an application, the end-user would like to receive a warning about premature degradation so that corrective actions can be planned well in advance. Nevertheless, even with an accurate SOH algorithm, a statistically significant deviation of the SOH would probably be detected (too) late.

Hence in many applications there is a need for a SOH predictor [5]. One type of predictor would record the whole history of the cell (voltage, current, temperature and SOC) and update an internal health model. The model in this predictor would require a large amount of experimental analysis.

2.5 CONCLUSION

In this white-paper the challenge of obtaining good reference data for SOH determination was established, and typical cell ageing tests as performed within EVERLASTING were explained. Interpreting the results of cell tests and applying those in life-expectancy forecasts of batteries, however, remains extremely complex.

2.6 REFERENCES

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