AKKU4FUTURE - MEASUREMENT METHODES FOR STATE INDICATION OF LITHIUM ION ACCUMULATORS

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ABSTRACT

Lithium ion batteries require a strict operation window in terms of terminal voltage, load current and cell temperature. Battery management systems (BMS) have to ensure the safe operation of lithium ion batteries. The functionality of such a BMS features the estimation of the state of the cell in terms and to provide some information (mostly the state of charge) to the user. The state indication is of high importance due to the fact that the knowledge about the health of the battery enables the BMS to act if the battery health gets worse, or even can slow down battery aging processes by acting preventively.

This paper describes measurement strategies to create data for the quantification of the state of charge (SOC) and the state of health (SOH) of a lithium ion battery. A measurement setup has been established to enable automated cycling of the test cells to age the rapidly. During cycling the cell capacity is monitored, because it is representative for the aging of the cell. The measurements are used to fit an equivalent electrical circuit. The derived parameters can be used to estimate the actual state of the cell. The understanding of the cell is the key to be able to design a sufficient and accurate state indication system.

1. INTRODUCTION

The aim of this paper is to show how relevant parameters are measured efficiently to estimate the state of a battery cell. Such parameters are the terminal voltage, the charge- and discharge current, the temperature of the cell and the time in use. These measureable parameters are used to calculate state indicating factors as they are the state of charge (SOC), the depth of discharge (DOD) and the state of health (SOH). The state indicators of a new cell and a used cell of the same type are compared. The amount of the difference provides the actual state the used cell.

To reliably estimate the state of a lithium ion battery data sets of a new cell are recorded. The Samsung ICR18650-22P [1] is the test cell; all the experiments are carried on. One data set contains the relation between the open circuit voltage and the state of charge. This enables the estimation of the state of charge of a new cell by the measurement of the open circuit voltage. To account for influencing factors like the terminal current and the cell temperature, the test cells are cycled with a parameter variation over the full safety operation window. By using the designed experiment method, the numbers of experiments which are necessary to cover the safety operation window are reduced to the number of 15. The dynamic behavior of the test cell is described by charging and discharging constant current pulses with a fixed capacity. In between the pulses, one hour is waited to let the chemistry inside the cells settle. The curvature of the terminal voltage during pulse and waiting time is an indicator of how the inner impedances behave.

2. MEASUREMENT METHODES

2.1 Correlation of open circuit voltage and state of charge at 25°C

Initially the test cell is charged at charge rate of 0,5C. The test cell is discharged and charged in 29 steps at a constant current pulse of 0,2C for a duration of 621s. In between each step a waiting time of up to 24h is inserted. Each package has a capacity of 74,14mAh. By the use of this strategy pairs of terminal voltage and state of charge values are generated for the charge and for the discharge. Because of electrochemical overpotentials inside the cell the charge and discharge course of the terminal votlage do not look the same. If these two voltage courses are overlayed and the arithmetic median is calculated, the correlation curve of the open circuit voltage and the state of charge is produced. This curve enables state of charge indication by measuring the cells terminal voltage. The final terminal voltage over state of charge correlation curve is shown in Figure 1. The y-axis represents the open circuit voltage which is scaled between 3V and 4,2V.

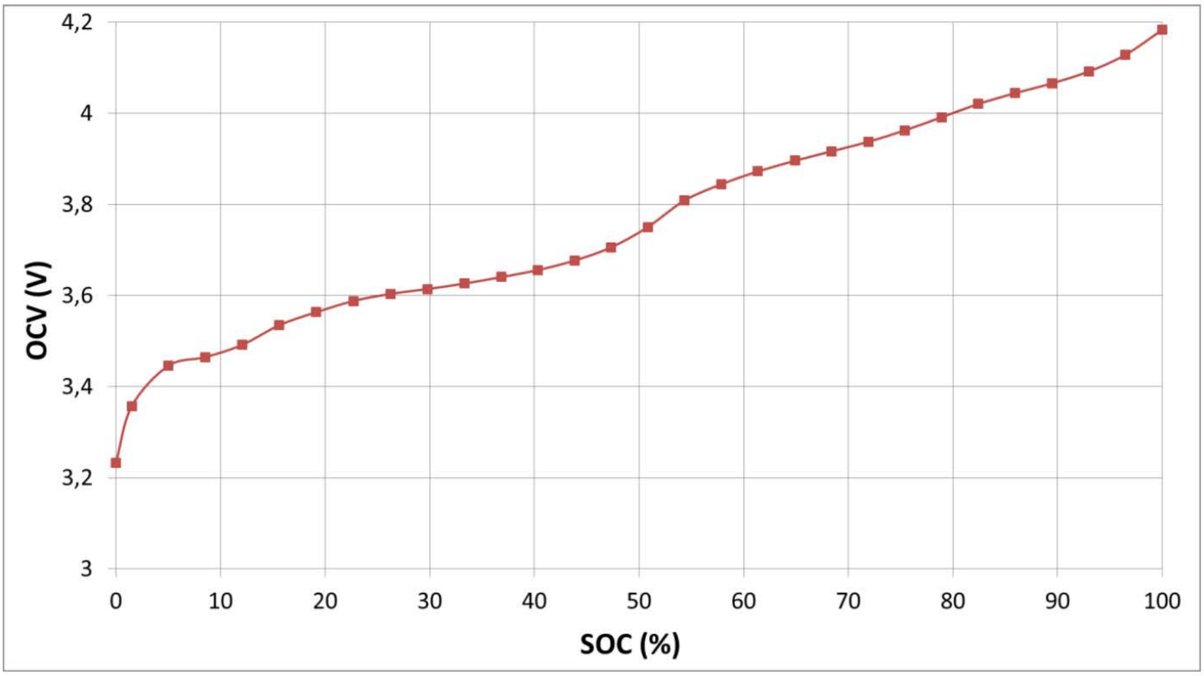

Figure 1: Relation between OCV and SOC at 25°C of Samsung ICR18650-22P test cell

2.2 Dynamic behaviour described via current pulses

To describe the test cell via Randles circuits [2] and more sophisticated equivalent circuits the model parameters have to bederrived from the above described mesurements. By imprinting a constant current the terminal voltage is monitored during the current pulse and after the pulse is finished. This is known as the voltage step response. This experiment is done in 15 variatinos of current and temperature. The charge and discharge current must be the same. The reconstitution of the terminal voltage gives knowledge of how the two main overpotentials (charge transfer, diffusion) inside the cell are behaving. The current pulses do charge the cell comletely respectively discharge the cell to a SOC of zero procent. Figure 2 shows the current pulses in the second row. -The internal resistance of the cell is derriced by the voltage step response. Highligthed in row three and four.

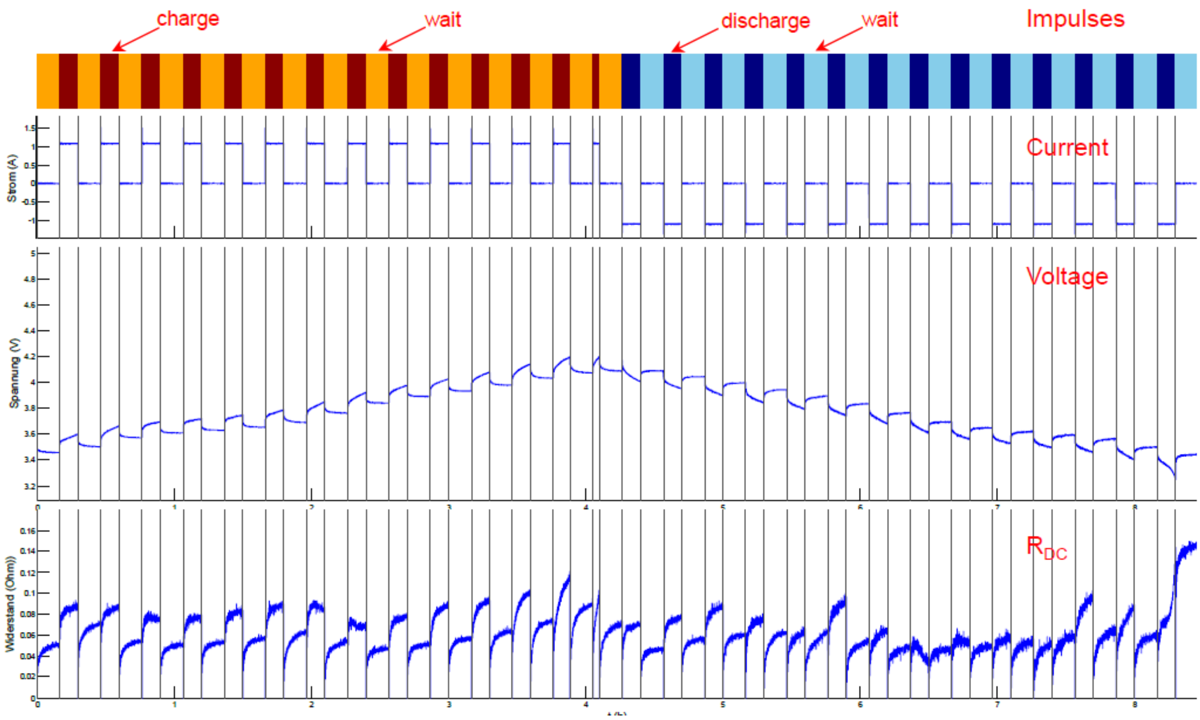

Figure 2: Current, voltage response and calculated DC resistance of the test cell

Figure 3 illustrates the equivalent ciruit used to describe the physical behaviour of the cell. The charge transfer, the SEI layer and the diffusion account for the dominant overpotentials.

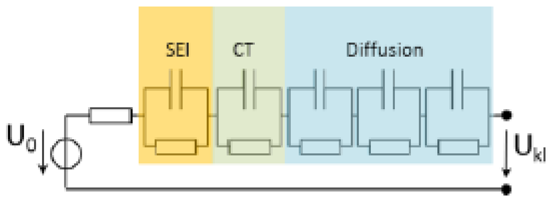

Figure 3: Equivalent circuit with 3 time constants

2.3 Cell degradation

The values for charge rate, discharge rat and surrounding temperature are varied whitin the data sheet spectrum to secure a accelarated aging of the cell. The statistical model behind the used method calculats the lowest number of experiments needed, to achieve the highest amount of expressiveness. This ensures a meaningfull decribtion of the cell throughout the operation area.. The set of variables in the 15 experiment is described in Table 1.

Table 1: Used parameter sets to describe the normal operation of the used cell

	Discharge Current [mA]	Temperature [K]	Charge Current [mA]
Experiment 1	5269	263	1344
Experiment 2	2456	277	1823
Experiment 3	8082	277	864
Experiment 4	8082	277	1823
Experiment 5	2456	277	864
Experiment 6	5269	298	538
Experiment 7	5269	298	2150
Experiment 8	538	298	1344
Experiment 9	5269	298	1344
Experiment 10	10000	298	1344
Experiment 11	8082	319	864
Experiment 12	2456	319	864
Experiment 13	8082	319	1823
Experiment 14	2456	319	1823
Experiment 15	5269	333	1344

The tests will show a decrease of capacity. Compared to the data sheet cycling durability forecast in Figure 4, the capacity retention occuring at each of the 15 experiments will differ. This will enable to build up a model, where the cell used in field can be compared to the data achieved by this cycling tests and to obtain a suiting value for battery state of health. Again based on the described euqivalent ciruits and its parameters linked to physical effects within the cell.

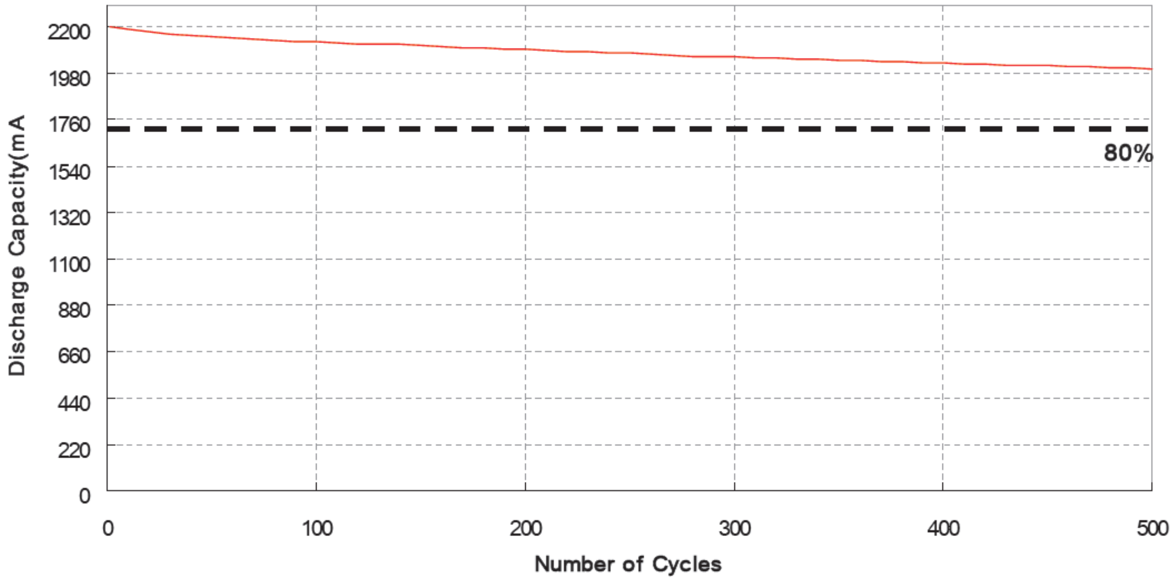

Figure 4: Samsung ICR18650-22P capacity retention by cyclic degradation [1]

3. THE TEST AND MEASUREMENT ENVIRONMENT

The established test stand comprises one Windows PC running NI LabView, two NI DAQ Cards, 6 active loads (AL) and 6 power supplies (PS). The PC controls the PS and AL continuously via USB to charge the test batteries with standard constant current – constant voltage (CC-CV) or constant current pulses, and to discharge the batteries in constant current (CC) or constant current pulse mode. Furthermore 6 Pt100 temperature converter cards are installed to monitor reach of the 6 test cells temperature. Three temperature conditioning devices keep the environmental temperature for the test cells constant. A schematic of the measurement equipment is shown in Figure 5.

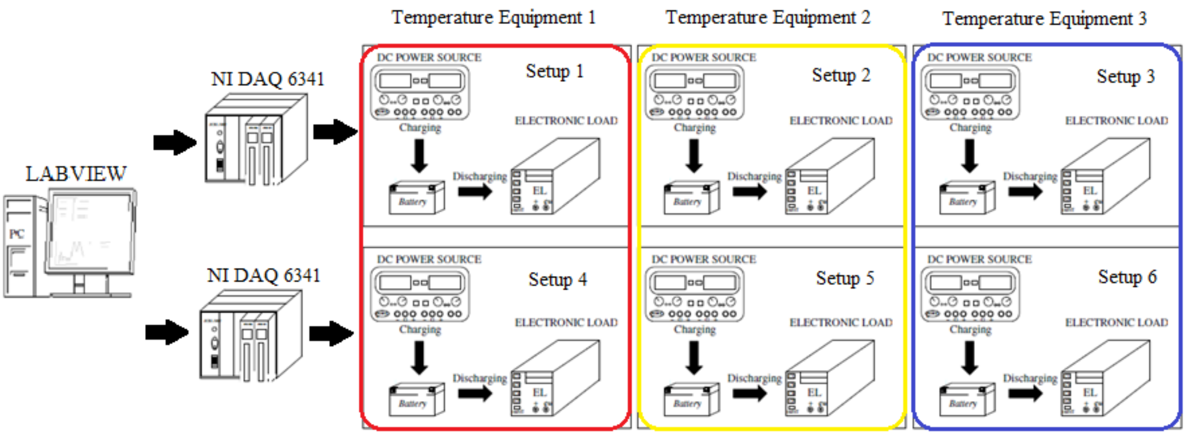

Figure 5: Schematic architecture of the used measurement equipment

The software structure to control the whole setup is build up in three independent loops. One to deal with the data aquisition, downsampling and data storage; one to observe the control structure and one loop to visualize the main data and the controls for the operator. Figure 6 shows schematically the relationships between the three main loops and which data are exchanged and the program flow.

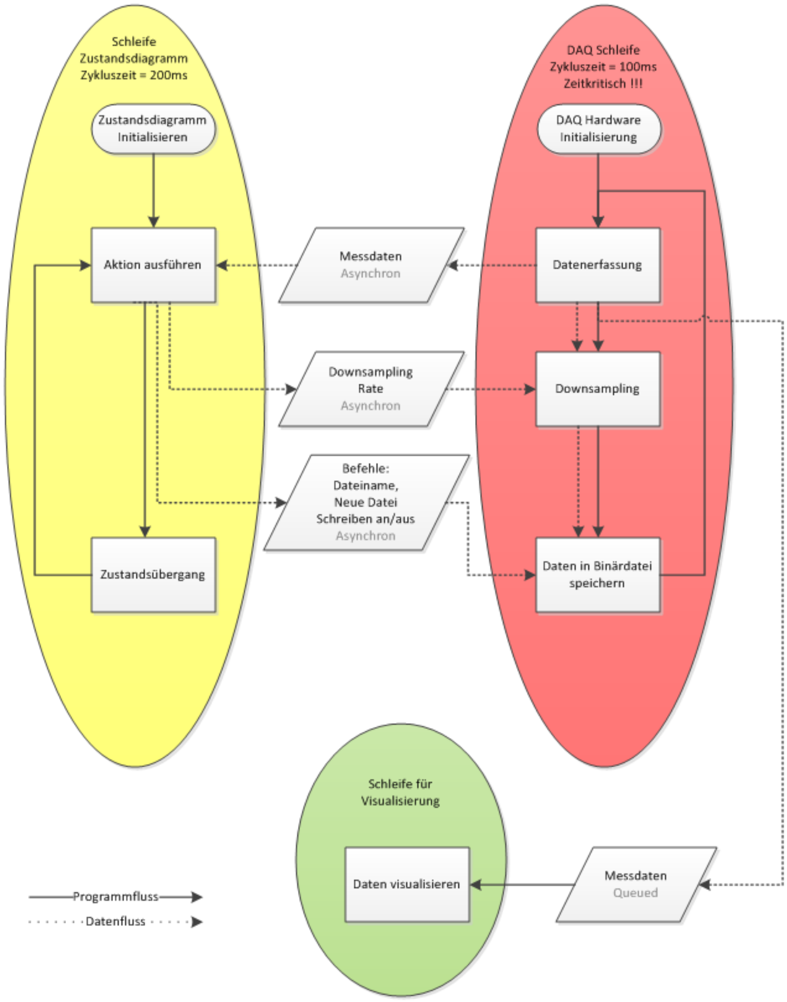

Figure 6: Software structure for controlling, data aquisition and GUI

4. RESULTS

The first measurements at temperatures of -10°C and 60°C show that the cell does not perform that efficient as the data sheet claims. At -10°C the test cell was damaged after 2 cycles due to copper solution in the electrolyte and dissolving on the electrodes leading to internal short circuit. Figure 7 compares the terminal voltage afte the 3rd and the 100th cycle at a temperature of 60°C.

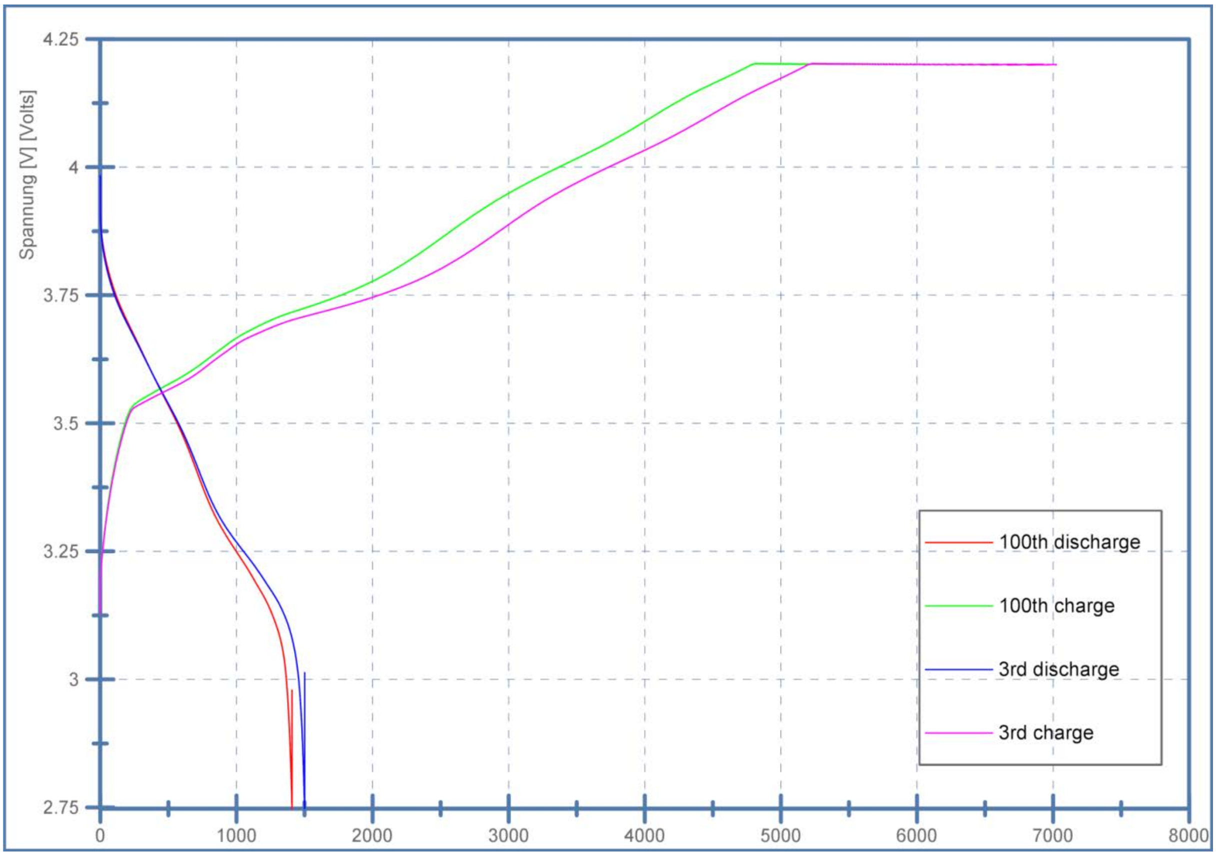

Figure 7: Capacity loss of test cell after 100 cycles at 0,63C charge and 2,54C discharge and 60°C

The voltage curves for charging (green and pink) show an increase of terminal voltage for the 100th charge cycle compared to the voltage curve of the third charge cycle. Therefore the charging process stops earlier because the cut-off criteria is reached faster . This means in total less capacity is charged into the cell at the 100th cycle.

A simmilar behaviour was found for the discharge. Again the terminal voltage decrases faster at the 100th cycle compared to the 3rd.

5. REFERENCES

[1] S. SDI, “Samsung Cylindrical ICR18650-22 Datasheet,” Samsung SDI Co., Ltd, 2010.

[2] J. E. B. Randles, “Kinetic of rapid electron reactions,” in Discussions of the Faraday Society, 1947.

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