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PROFESSIONAL PAPER

Akku4Future - Measurement Methods to gather data for computing state indication

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

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

Keywords: state of charge (SOC), state of health (SOH), Li-Ion, Nickel-Manganese-Cobalt Oxide cathode (NMC)

Akku4Future – merilne metode za ugotavljanje stanja akumulatorjev

Za optimalno uporabo litij-ionskih akumulatorjev je potrebno imeti natančne podatke o napetosti na sponkah, bremenskemu toku in temperaturi akumulatorskih celic. Varno uporabo zagotavlja sistem za upravljanje akumulatorjev BMS. Funkcionalnost sistema omogoča uporabniku informacijo o stanju (napolnjenosti) akumulatorja. Informacija o stanju akumulatorja je pomembna tudi za sistem BMS, saj lahko s pravilnim nadzorom akumulatorjev vplivamo na njihovo obratovalno dobo in upočasnimo postopek staranja.

V članku so predstavljeni merilni postopki za ugotavljanje napolnjenosti akumulatorjev in splošnega stanja akumulatorjev. Z merilno opremo smo izvedli postopek avtomatskega polnjenja in praznjenja za pohitritev staranja akumulatorjev. Na osnovi meritev smo zasnovali električno vezje, na osnovi katerega lahko ocenimo stanje posamezne celice. Razumevanje stanja celic je ključnega pomena za zasnovo učinkovitega in točnega sistema za prikaz stanja.

1 INTRODUCTION

The aim of the paper is to show how the relevant parameters are measured efficiently to estimate the state of a battery cell. Such parameters are the terminal voltage, charge/ and discharge current, temperature of the cell and time in use. These measureable parameters are used to calculate the state indicating factors, such as the state of charge (SOC), the depth of discharge (DOD) and state of health (SOH). The state indicators of a new and used cell of the same type are compared. The amount of the difference provides the actual state of 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 SOC. This enables the estimation of the SOC of a new cell by measuring the open-circuit voltage. To account for the affecting 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 number of the experiments necessary to cover the safety operation window is reduced to 15. The dynamic behavior of the test cell is described by charging and discharging the 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 the pulse and waiting time is an indicator of how the inner impedances behave.

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2 MEASUREMENT METHODS

2.1 Correlation between the open-circuit voltage and SOC at 25°C

Initially, the test cell is charged at the charge rate of 0.5C. The test cell is discharged and charged in 29 steps at a constant-current pulse of 0.2C for 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 using this strategy pairs of terminal voltage and state of charge values are generated for the charge and discharge. Because of electrochemical over potentials inside the cell, the charge and discharge course of the terminal voltage 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 the SOC indication by measuring the cells terminal voltage. The final terminal voltage over the SOC correlation curve is shown in Figure 1. The y-axis represents the open circuit voltage which is scaled between 3V and 4.2V.

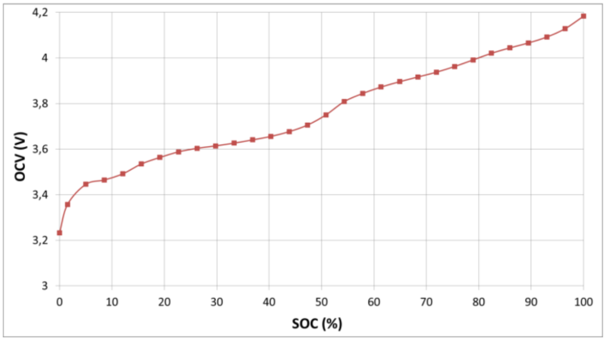

Figure 1 Relation between SOC and OCV at 25°C for Samsung ICR18650-22P.

2.2 Dynamic behavior described via the current pulses

To describe the test cell via the Randles circuits [2] and more sophisticated equivalent circuits, the model parameters have to be derived from the above described measurements. 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 for 15 variations in the current and temperature level. The charge and discharge current must be the same. The reconstitution of the terminal voltage gives the knowledge of how the two main over-potentials (charge transfer, diffusion) inside the cell behave. The current pulses either charge the cell completely or discharge the cell to a SOC of zero percent. Figure 2 shows the current pulses in the second row. The internal resistance of the cell is derived by the voltage-step response.

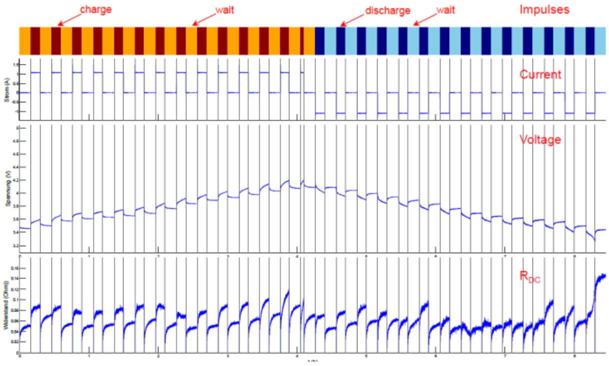

Figure 2 Current, voltage response and calculated DC resistance of the test cell.

Figure 3 illustrates the equivalent circuit used to describe the physical behavior of the cell. The charge transfer, SEI layer and diffusion account for the dominant over-potentials.

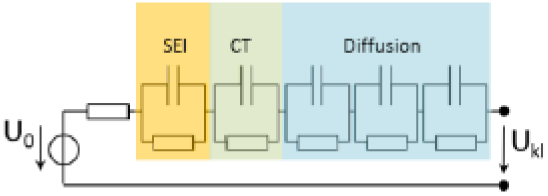

Figure 3 Equivalent circuit with three time constants.

2.3 Cell degradation

The values for the charge rate, discharge rate and ambient temperature are varied within the data sheet spectrum to secure an accelerated aging of the cell. The statistical model behind the used method calculates the lowest number of the experiments needed to achieve the highest amount of expressiveness. This ensures a meaningful description of the cell throughout the operation area. The set of variables used in the 15 experiments is described in Table 1.

The tests show a decrease in the capacity. Compared to the data-sheet cycling durability forecast in Figure 4, the capacity retention occurring at each of the 15 experiments differs. This enables to build up a model, where the cell used in the field can be compared to the data achieved by these cycling tests and to obtain a suitable value for the battery SOC.

Table 1: The used parameter sets describing the normal operation of the test cell

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

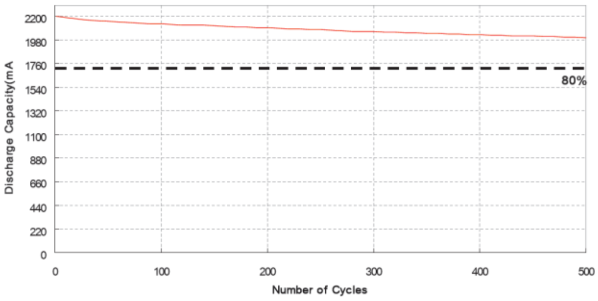

Figure 4 Samsung OCR18650-22P capacity retention by cyclic degradation [1].

2.4 *The test and measurement environment*

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

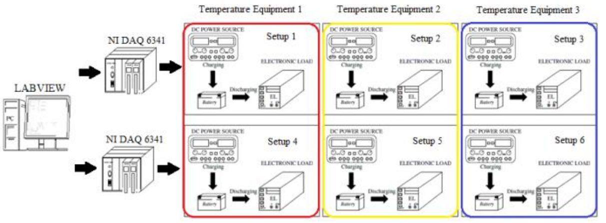

Figure 5 Schematic architecture of the used measurement equipment.

The software structure to control the whole setup is built up in three independent loops: one to deal with the data acquisition, down sampling and data storage; one to observe the control structure; and one to visualize the main data and the controls for the operator. Figure 6 shows schematically the relationships between the three main loops, data exchange and program flow.

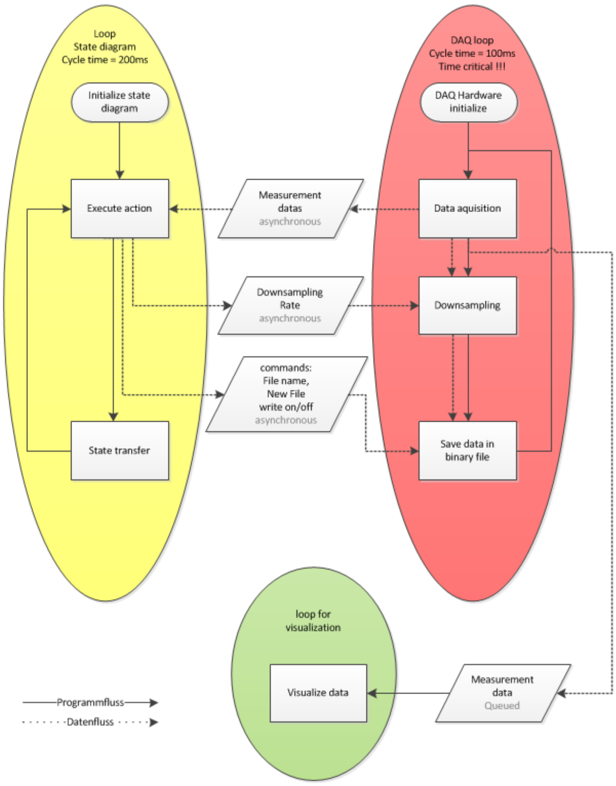

Figure 6 Software structure for controlling, data aquisition and GUI.

3 RESULTS

The first measurements taken at temperatures of -10°C and 60°C show that the cell does not perform as efficient as declared on the manufacturer data sheet. At -10°C, the test cell got damaged after two cycles due to copper solution in the electrolyte and dissolving on the electrodes leading to internal short circuit. Figure 7 compares the terminal voltage after the 3rd and the 100th cycle at the temperature of 60°C. The voltage charging curves (green and pink) show an increase in the 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 are reached faster. In total this means that less capacity is charged into the cell at the 100th cycle than at the third one.

A similar behavior was found for the discharge. Again, the terminal voltage decreases faster at the 100th cycle compared to the 3rd.

REFERENCES

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Alexander Elbe, MSc, studied Electrical Energy and Mobility Systems at the Carinthia University of Applied Sciences and graduated with MSc in 2013. His thesis was written within the research project Akku4Future where he developed measurement strategies to take electrochemical processes inside the lithium ion cell into account to identify the state of charge and the state of health. Since 2012, he has been working as junior researcher at the CUAS where he is the contact person for EV traction battery topics.

Florian Niedermayr, PhD, studied Electrical and Biomedical Engineering at the Technical University of Graz. After his graduation he worked as an assistant professor at the department of Health Care Engineering where his focus was on modeling and simulation of electromagnetic fields and digital human models. At his current position at Fraunhofer-Italia-Research his focus is on automation. His current research does include among others smart buildings.

David Zander, MSc, studied Remote Systems at the Carinthia University of Applied Sciences and graduated with MSc in 2014. His thesis was written within the research project Akku4Future where he developed an automated, remote visible test environment for measuring the lithium batteries. Since 2014 he has been working at Infineon Technologies Austria GmbH as a field application engineer implementing measurement systems for automotive applications.

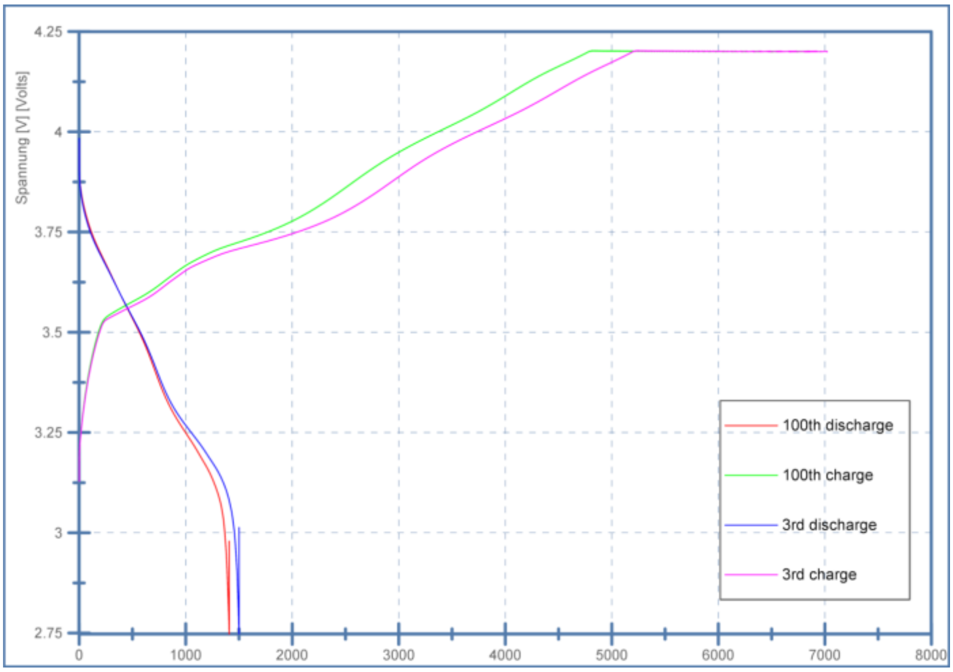

Figure 7 Capacity loss of the test cell after 100 cycles at a 0.63C charge, 2.54C discharge and 60°C.