# Setup and Parametrization of Battery Models

-Measurement, Modeling and Parametrization-

At *FA* Battery Engineering, we have a deep commitment to understanding battery technology and its behaviour. Among the numerous services we provide, one of our key competencies is in battery modelling and parametrization. Independent of the target application, whether it is a battery system for stationary application or a battery system for electric mobility, we support our customer with our high-fidelity models and over a decade of experience to **choose** a right battery cell and **build**+**parametrize** the model for a specific application. Our competency covers every type of batteries, either it's a cylindrical cell, prismatic cell or a pouch cell.
We support our customers at following steps:
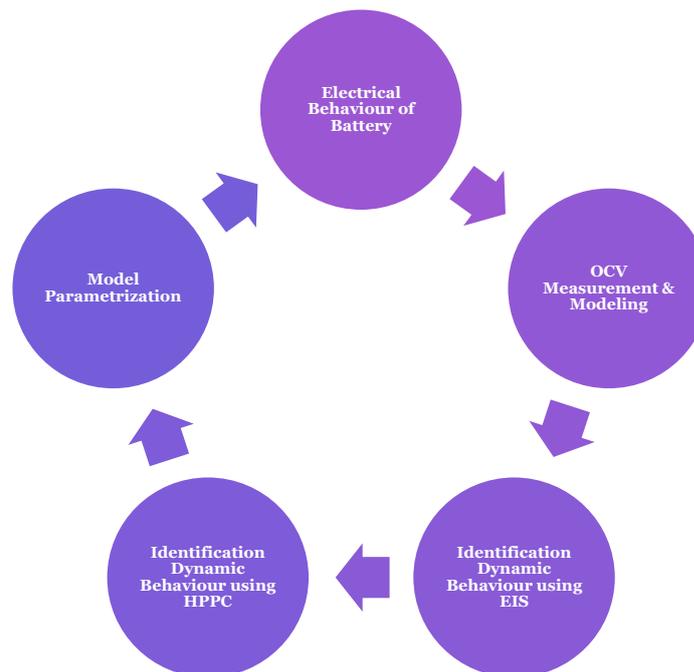
To identify the dynamic behaviour of lithium-ion batteries, the method of electrical impedance spectroscopy (EIS) is a suitable choice. Here, the battery is subjected to an excitation signal, which is typically sinusoidal, and the resulting system response is measured. A distinction is made between galvanostatic impedance spectroscopy, where a current is applied, and the resulting voltage response is measured, and

potentiostatic impedance spectroscopy, where a voltage signal is prescribed, and the resulting current response is captured. In galvanostatic impedance spectroscopy, the sinusoidal current (RMS value I_{ac}) is often superimposed with various direct currents (I_{dc}) to capture the electrochemical battery behaviour under different current loads. A prerequisite for the application of impedance spectroscopy is that the investigated system is linear and time-invariant. Batteries generally exhibit highly nonlinear behaviour over the state of charge range. Therefore, it is important to ensure during the application of EIS that the state of charge does not change significantly during the measurements, so sufficient linearity around the current operating point is maintained. From the relationship between voltage and current signals, the corresponding impedance is then determined. Impedance reflects amplitude amplification and phase shift. It is measured at various frequencies, ranging from several kilohertz down to the millihertz range, to capture the impedance spectrum of the battery. Figure 1 shows a characteristic impedance spectrum of a lithium-ion battery of LTO/NMC cell.
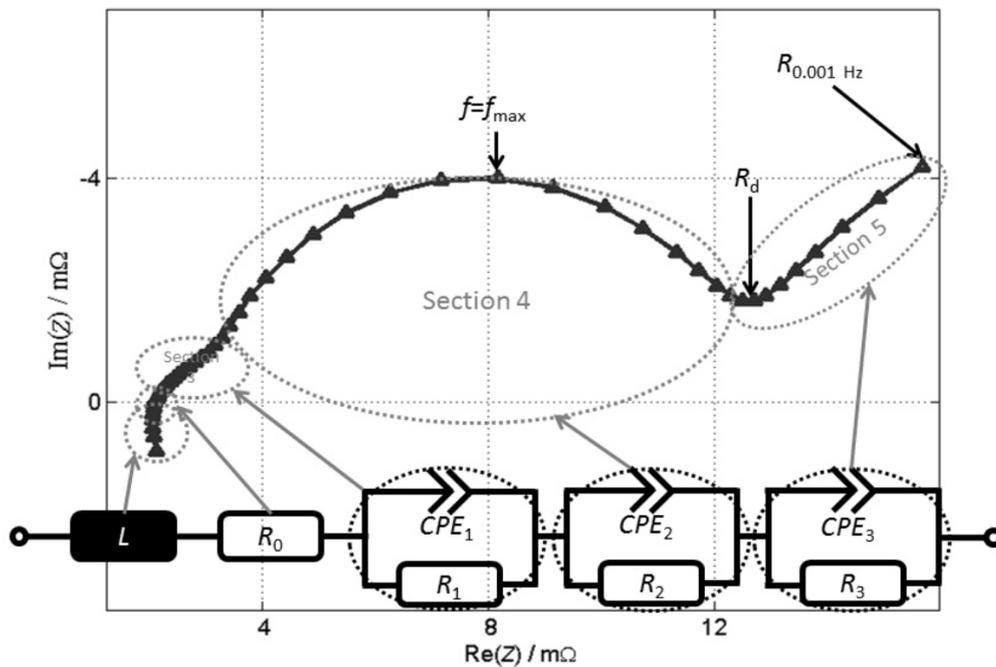

Figure 1 Typical Nyquist plot of LTO/NMC lithium-ion battery measured at -20 °C and 50% State-of-Charge, frequency range: 5 kHz – 1 mHz

Model Parametrization

The individual components of the equivalent circuit must be parametrized according to the required dependencies on temperature, state of charge, and current. The open-circuit voltage curve is typically stored in the model as a state-of-charge-dependent tabular dataset, from which the open-circuit voltage is determined via interpolation based on the current state of charge. For parameterizing the dynamic effects of the battery, suitable lookup tables or approximation functions (e.g., polynomials) must also be determined, which include the relevant dependencies. Depending on the available measurement technology, maximum duration, and accuracy requirements, various parameterization methods are suitable for capturing these dependencies:

1. Electrochemical Impedance Spectroscopy: Capturing the battery parameters using electrical impedance spectroscopy represents the most complex parameterization method, since the measurements take a comparatively long time and the equipment is expensive. It is particularly suitable for detecting highly dynamic processes in the area of the SEI passivation layer as well as charge transfer and double-layer capacitance. Diffusion effects can only be captured with this measurement method with difficulty, due to the required low frequencies below 1 mHz and the resulting enormous measurement duration.
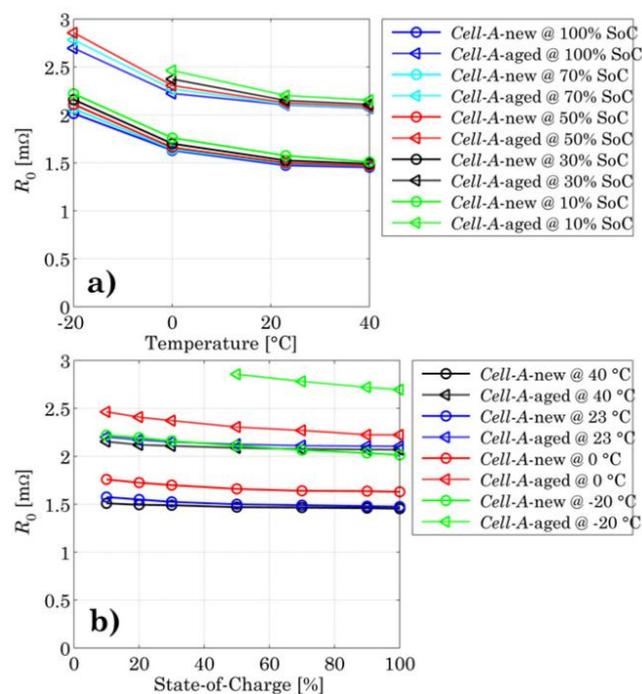

Figure 2 Ohmic resistance of LTO/NMC-new and LTO/NMC-aged: a) dependence on temperature b) dependence on SOC

2. Parameterization Using Current Pulses: The second common method for parameterizing battery dynamics is the analysis of voltage responses following current pulses. From the rise and fall of overvoltages resulting from various dynamic effects, the corresponding resistance values and time constants of the RC elements can be determined. This works in principle for both high and low frequencies. Only for effects with very short time constants (such as the SEI layer) are there limitations if the measurement equipment cannot record the voltage response with a sufficiently high sampling rate in the kilohertz range. Just like impedance spectroscopy, current pulses are applied at different states of charge, temperatures, and current levels to capture the relevant dependencies. In both parameterization methods presented, the actual identification of the model parameters is carried out by a nonlinear optimization process.

Verification & Validation of Battery Models

To validate the battery models, the results of the battery simulation are compared with real measurement data. Different datasets must be used here than those used for parameterization.

In the following example (Fig. 3), a model consisting of a state-of-charge-dependent voltage source, a resistor, and an RC element is considered. The parameterization was carried out using EIS & HPPC Tests to determine the total resistances to parameterize the RC element, which mainly represents diffusion effects. The parameters were stored in value tables depending on the current.
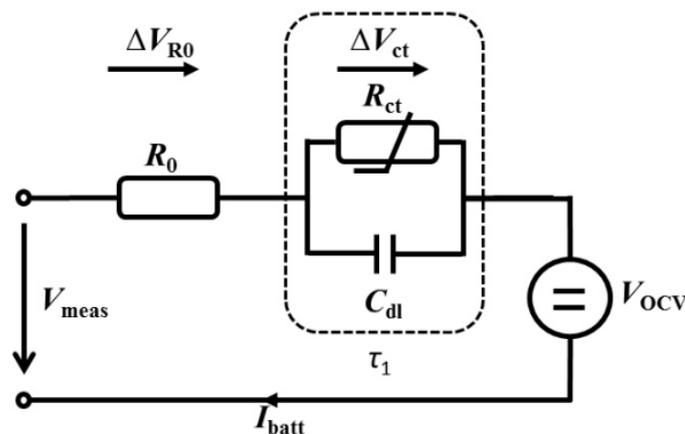

Figure 3: Nonlinear first order lithium-ion battery model commonly employed in battery management systems

Summary

FA Battery Engineering supports your team with advanced system engineering and modelling/simulation methods. Whether in E-Mobility or Stationary systems, we assist at various stages of your development projects. With 15 years of experience in battery system engineering for automotive and stationary BESS applications, we provide expert solutions.

For enquiries, contact us at info@fa-battery.com.