Battery Relaxation Effects

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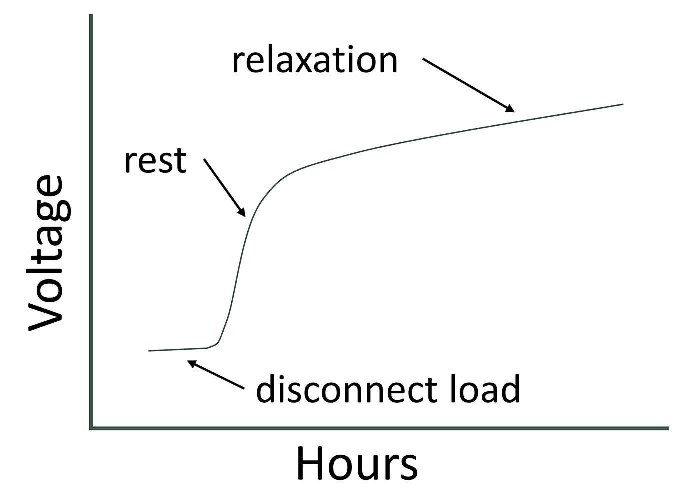
WHAT IS BATTERY RELAXATION?

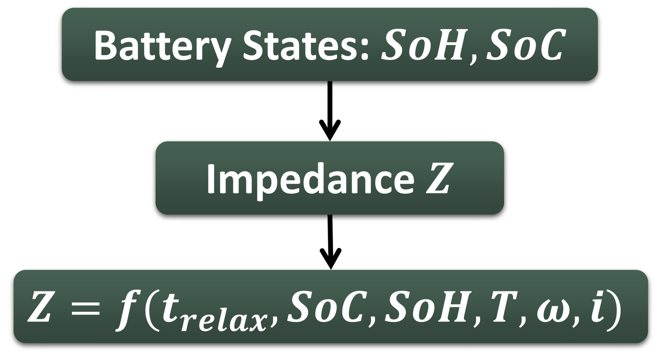
When discharge current it removed from a battery, the voltage jumps initially and continues to rise slowly over many hours. This slow voltage rise is known as the **relaxation effect**.

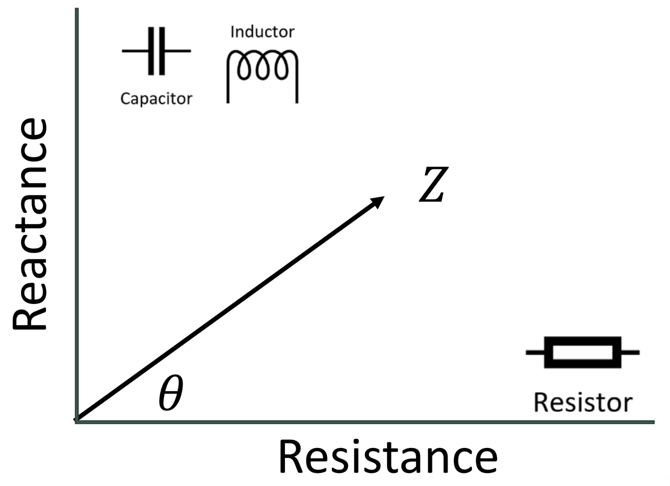
In **lithium-ion** batteries, different lithium-ion concentration gradients exist throughout the battery after discharge or charge is stopped. These concentration gradients naturally tend to equalize themselves over time.



WHY DOES RELAXATION MATTER?

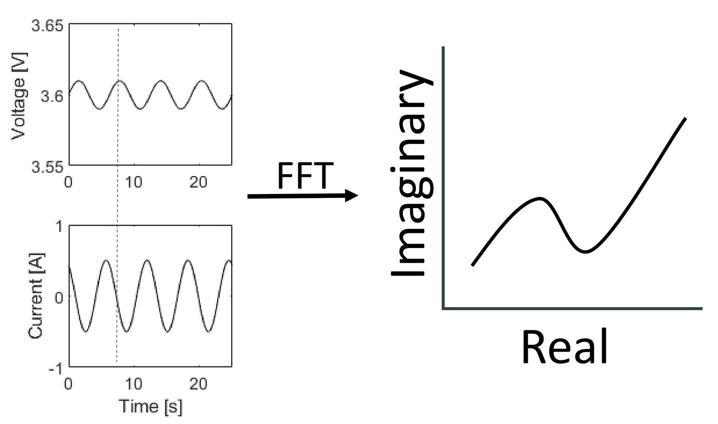
The state of health (**SoH**) and state of charge (**SoC**) of a battery are related to its **impedance** Z at a temperature $\boldsymbol{T}$ and applied current $\boldsymbol{i}$ at frequency $\boldsymbol{\omega}$. Z also changes with **relaxation time** t_{relax}. Therefore, consistent impedance measurements can only be obtained if the relaxation effect is known.





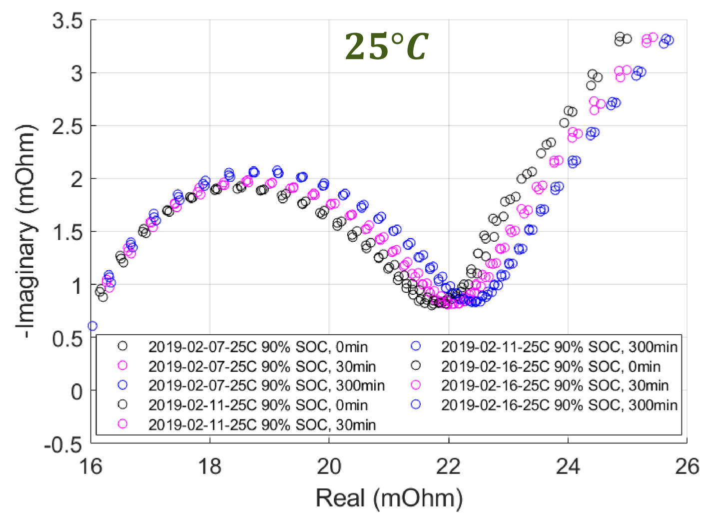
EIS

A technique called **Electrochemical impedance spectroscopy (EIS)** is used to measure battery **impedance**. By applying sinusoidal current signals at different frequencies, a voltage response is measured. The magnitudes and phase shifts of the response are converted to complex impedance using the fast Fourier transform (FFT).



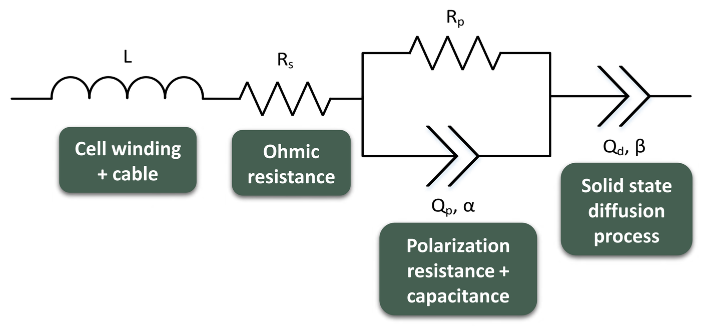
EIS & REPEATABILITY

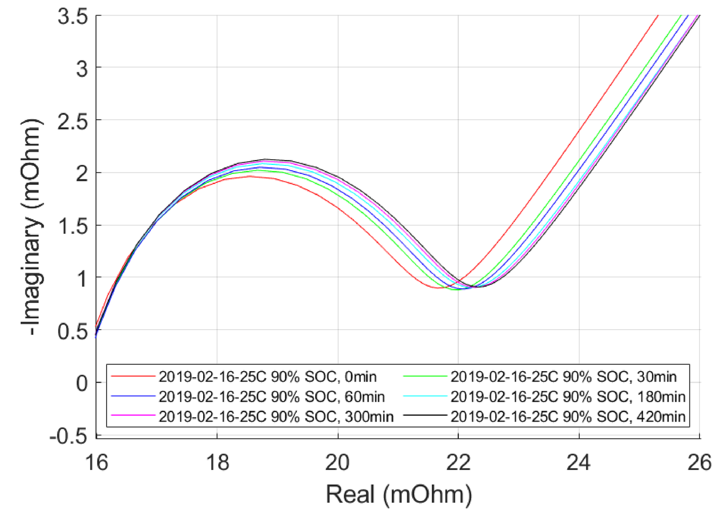
Relaxation tests were repeated on three different days (for the same battery). The results show that the relaxation effect is **repeatable** under constant conditions. The repeatability error is small enough to still distinguish relaxation effects.



IMPEDANCE MODELLING

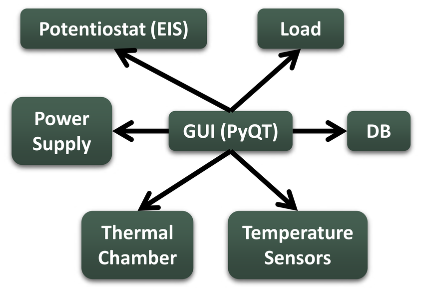
To understand how different physical battery components are affected by the relaxation effect, an **impedance model** was fit to the EIS data [1].

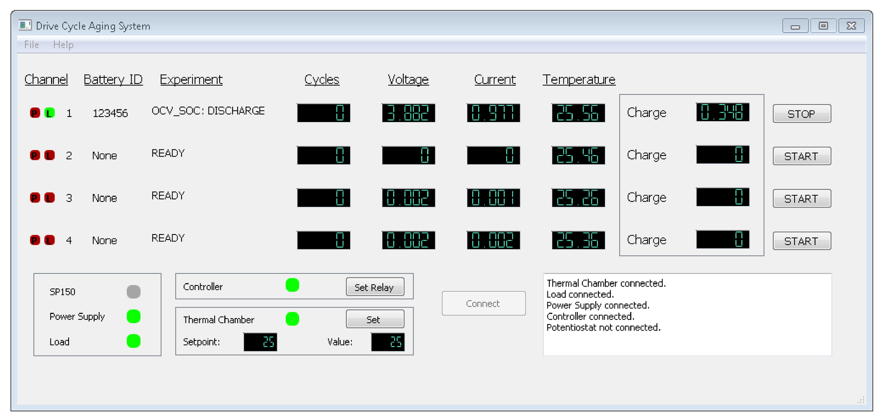




EXPERIMENTAL

A **custom software** (Python) was developed to orchestrate the test procedures using different devices. A **Samsung INR21700-48G** (4.8 Ah) cylindrical cell was used as the test subject.



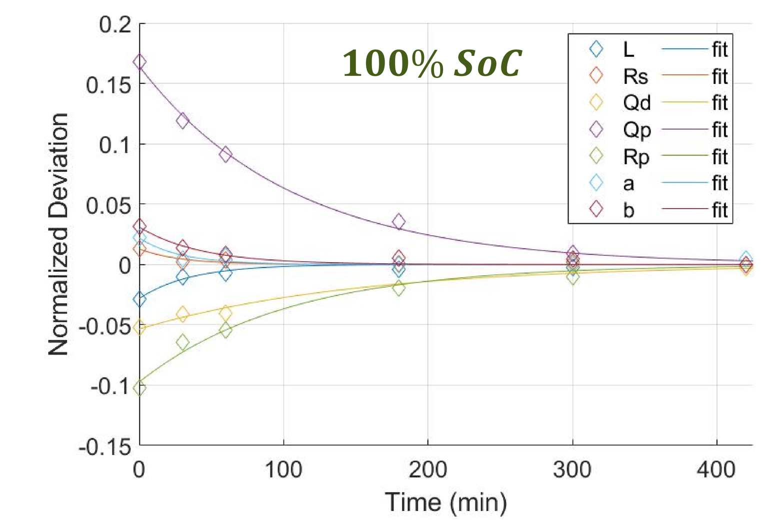


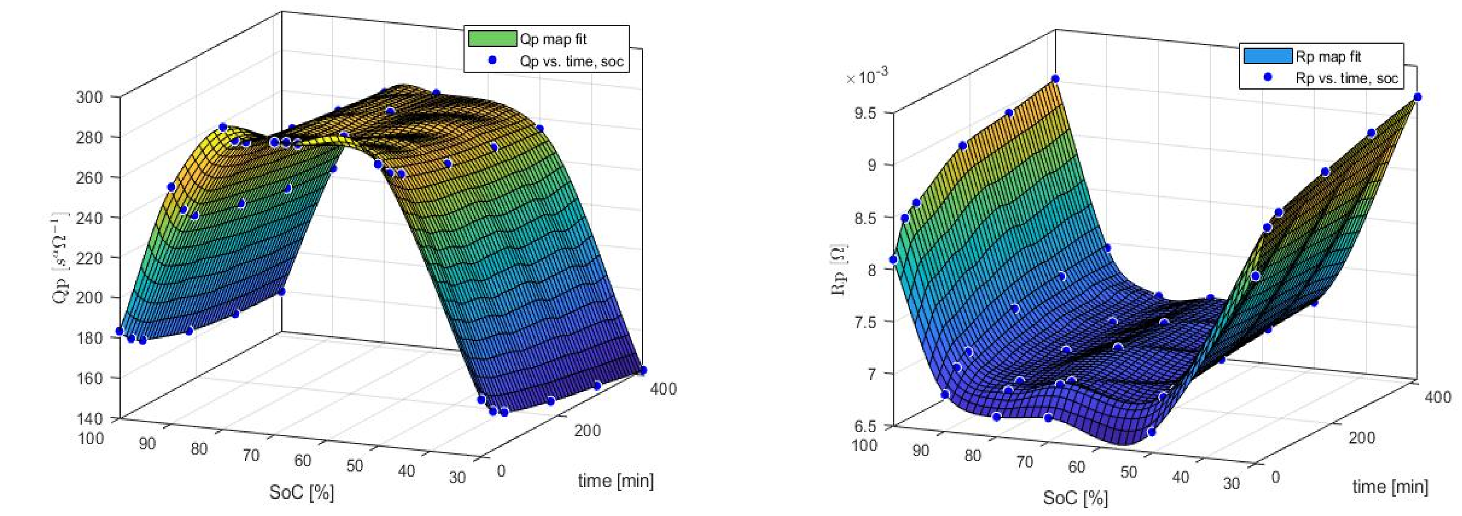
RELAXATION & SoC

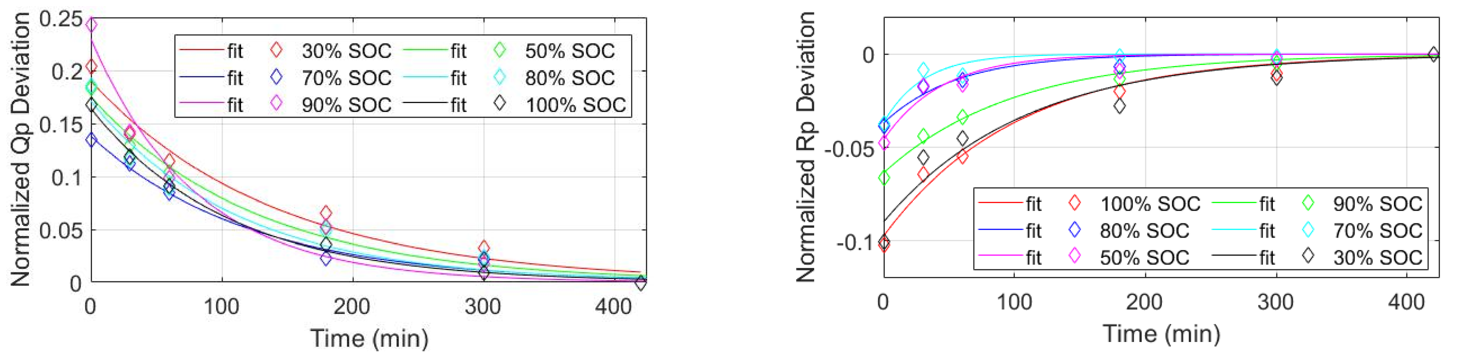
The changes in impedance model parameters were mapped over relaxation time and SoC.

Deviation from the relaxed state was calculate for each model parameter [2]. The contribution of L, a, b, and Rs to the relaxation effect are small. Qp, Qd, and Rp still change after 7 hours.

The relaxation time is similar across different SoCs for Qp, but changes for Rp with SoC.







FUTURE WORK

- Reproduce results for a different cell of the same battery type.
- Expand temperature range.
- Explore how discharge rate affects relaxation.
- Compare relaxation effect after charge.
- Investigate impact of aging on relaxation effect.
- Compare relaxation effects of different types of batteries.
- Explore additional impedance models.

REFERENCES

[1] J. Schmitt, A. Maheshwari, M. Heck, S. Lux, M. Vetter, Impedance change and capacity fade of lithium nickel manganese cobalt oxide-based batteries during calendar aging, J. Power Sources. 353 (2017) 183–194. doi:10.1016/j.jpowsour.2017.03.090.

[2] F.M. Kindermann, A. Noel, S. V. Erhard, A. Jossen, Long-term equalization effects in Li-ion batteries due to local state of charge inhomogeneities and their impact on impedance measurements, Electrochim. Acta. 185 (2015) 107–116. doi:10.1016/j.electacta.2015.10.108.

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