www.pulsenics.com | 184 Pearl St, Toronto, ON

Electrochemical Impedance Spectroscopy for Battery State-of-Charge (SOC) prediction

By Dr. N. Patterson

1. Introduction

Li-ion batteries used for Electric Vehicles (EV) and other Electrified Mobility (EM) systems have significantly different discharge cycles than their consumer electronics battery counterparts. The main distinction is that **EV and EM batteries are expected to operate under dynamic loads, which often vary based on driving speed, trip distance, and season.**

The unpredictable power requirements in day-to-day driving makes accurate predictions of state-of-charge (SOC) difficult. Presently, the most common methods of estimating SOC use coulomb counting and cell voltage lookup tables, but these have certain drawbacks. **Without regular recalibrations, these methods quickly lose track of the true SOC, leading to unacceptable range estimation**.

Coulomb counting estimates the amount of charge transferred into or out of the cell relative to a known initial SOC. **Uncertainty in the initial SOC or inaccurate current measurements exacerbated by variable current causes estimation errors to propagate**. Recalibration resets the drifting SOC estimate, but this may be inconvenient to perform often and can take a long time to complete.

Electrochemical impedance spectroscopy (EIS) adds value to the SOC estimate methodology. EIS is a non-intrusive, non-destructive method which measures the impedance of electrochemical cells such as batteries. Cell impedance is the result of different electrochemical processes within the cell that shuttles charge back and forth. **EIS is known to be sensitive to changes in SOC and state-of-health (SOH), making it a powerful tool for estimating these parameters.**

2. Case study: Li-ion batteries under dynamic current

Pulsenics EIS hardware is specifically designed to run on dynamically loaded cells. This allows EIS data to be captured *in-operando* during dynamic cycling which is then analyzed to identify indicators that improve SOC estimates. EIS on potentiostats is not suitable for live or dynamic current operation as they often run into significant noise and non-linearity disturbances. Figure 1 shows a 28-hour long dynamic profile along with real-time changes to the circuit fitting parameters extracted from EIS. These parameters relate to components (i.e. electrolyte resistance) and reactions (i.e. faradaic resistance) within the cell.

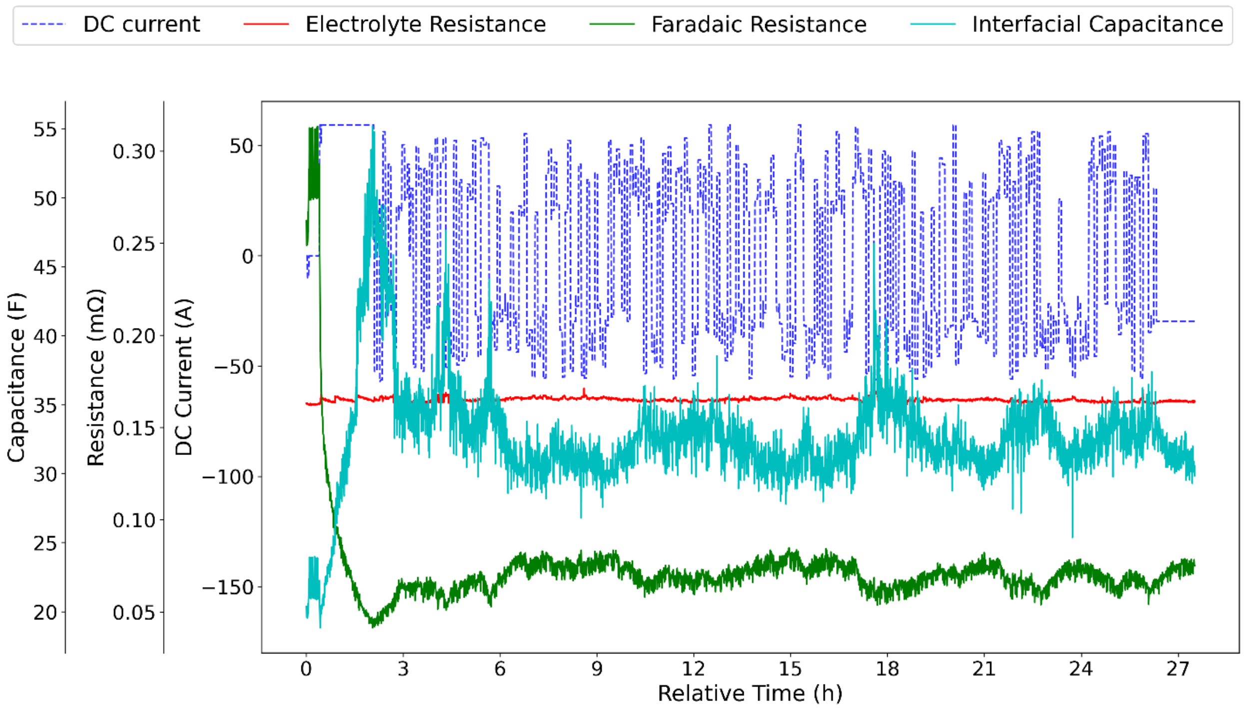

Figure 1: Dynamic cycle profile combined a mix of charging and discharging currents. Changes to the fitting parameters in the Randles circuit model are tracked over the duration.

Forward coulomb counting was used to track the SOC over the course of this variable power cycle. Figure 2 shows how the SOC changed over time using this method. At the end of the cycle, a single backward coulomb count was performed to verify the estimate. **The forward coulomb count method underestimated SOC by 30,000 ppm (3 %) by the end of the 28-hour period**.

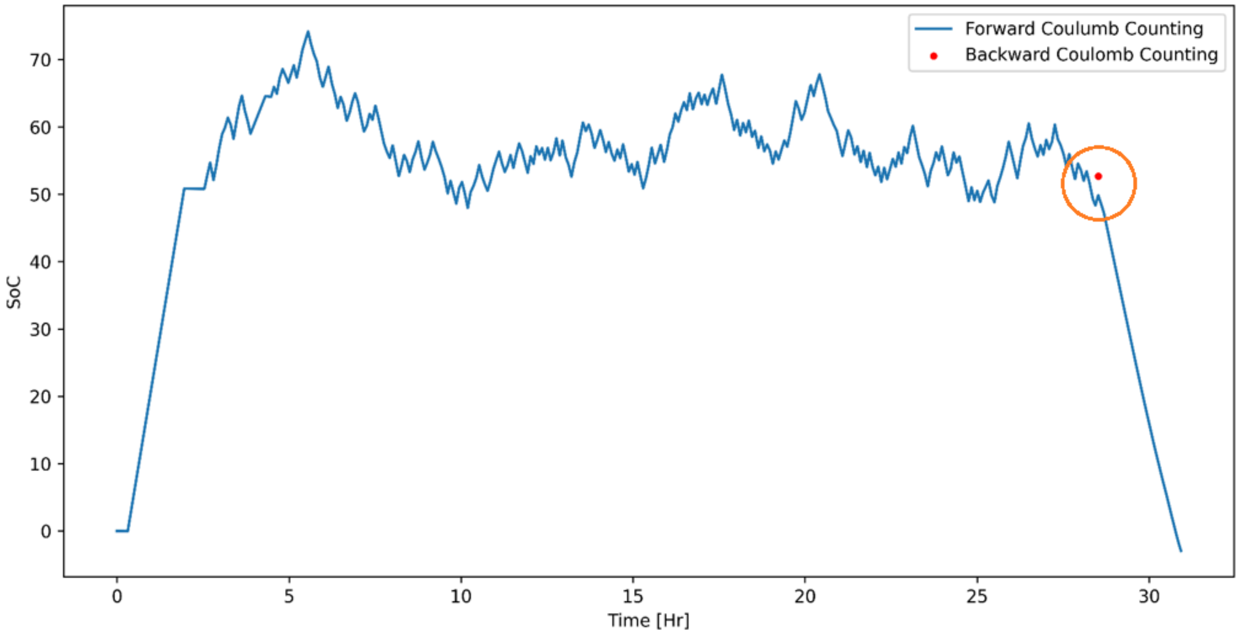

Figure 2: Estimate of SOC over the profile duration using forward coulomb counting. The backward coulomb count value is circled in orange.

To improve the estimate, **a simple algorithm was developed that utilizes additional EIS data to more accurately evaluate the true SOC**. Pulsenics EIS takes *in-operando* measurements which retains the ability to provide real-time SOC estimates as seen in Figure 3. At the seven-hour mark, EIS-SOC begins to deviate from coulomb-counting SOC and continues for the rest of the profile duration. By the end of 28 hours, the SOC estimate using **EIS-SOC matches the value from backward coulomb counting, giving an error of 4.7 ppm (0.00047 %)**.

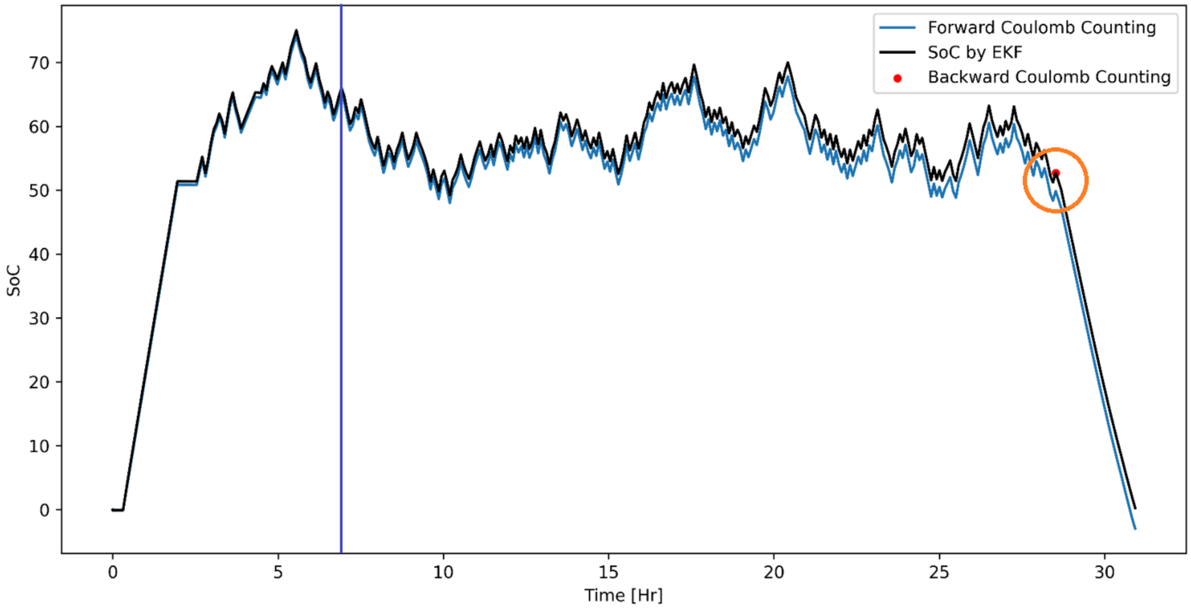

Figure 3: Addition of EIS derived electrochemical data improves real-time SOC estimation, reaching good agreement with the backward coulomb count at the end of the dynamic profile.

3. Conclusion

This initial study shows the capability of Pulsenics in-operando EIS for improving SOC estimates of EV and EM batteries under dynamic conditions. The ability to extract key indicators that are tied to present conditions within the battery results in more accurate estimates of SOH and SOC. Additionally, the estimated accuracy is maintained for a significantly longer time, reducing the need for regular recalibration checkups.

To learn more about battery measurements with Pulsenics EIS, visit pulsenics.com or book a call with us.