Sensitivity of cell terminal voltage to ESR

- A common approach to estimating SOH is to compute estimates of equivalent-series resistance and total capacity
- Estimating ESR R_0 turns out to be relatively simple because it is highly "observable" from voltage measurements
- Consider $v_k = \text{OCV}(z_k) + Mh_k - \sum_i R_i i_{R_i,k} - i_k R_0$
- Define the sensitivity of the voltage measurement to a change in resistance as

$$S_{v_k}^{R_0} = \frac{R_0}{v_k}\frac{\mathrm{d}v_k}{\mathrm{d}R_0} = \frac{-R_0}{v_k} i_k$$

- Since i_k can be very large, absolute sensitivity is high

Sensitivity of cell terminal voltage to ESR

- One approach to estimating R_0 is to compare voltages at two adjacent time samples

$$\begin{aligned} v_k &= \text{OCV}(z_k) + Mh_k - \textstyle\sum_i R_i i_{R_i,k} - i_k R_0 \\ v_{k-1} &= \text{OCV}(z_{k-1}) + Mh_{k-1} - \textstyle\sum_i R_i i_{R_i,k-1} - i_{k-1} R_0 \\ \hline v_k - v_{k-1} &\approx R_0 (i_{k-1} - i_k), \end{aligned}$$

  where SOC, v_{C_i} and h_k change relatively slowly compared with rate of change of i_k
- So, we can estimate

$$\widehat{R}_{0,k} = \frac{v_k - v_{k-1}}{i_{k-1} - i_k}.$$

Issues (1–2)

ISSUE I: Can compute $\widehat{R}_{0,k}$ only when $\Delta i_k \neq 0$. So, we skip updates when $|\Delta i_k|$ is small (avoids amplifying noise, as well)

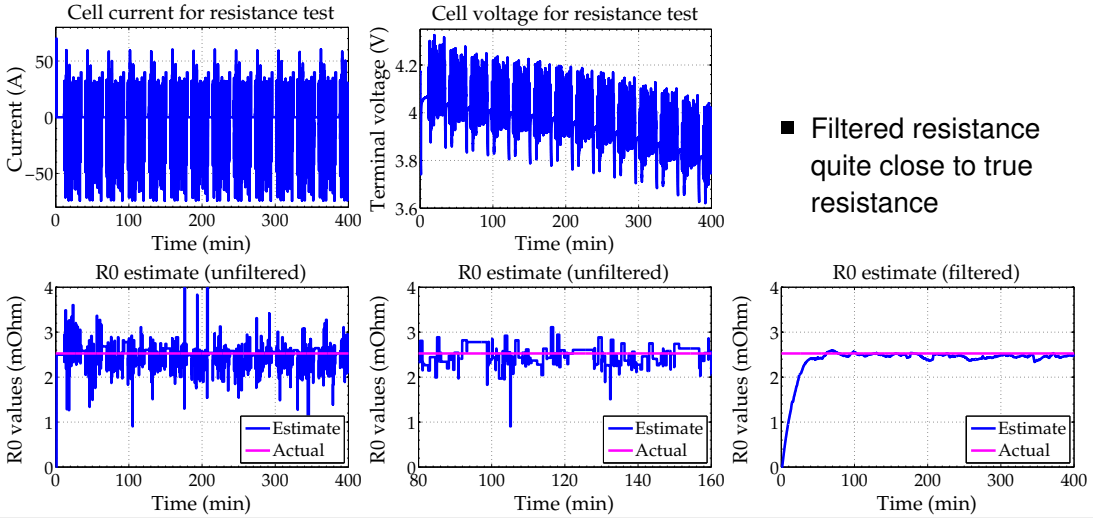
ISSUE II: Because ESC model has imperfect fidelity with respect to true cell, and because of inaccuracy introduced via specific approximations, $\widehat{R}_{0,k}$ is quite noisy

- Might consider using total least squares approach (see later re. total capacity estimation) but can also simply filter. For example (where $0 \ll \alpha < 1$)

$$\widehat{R}_{0,k}^{\text{filt}} = \alpha \widehat{R}_{0,k-1}^{\text{filt}} + (1-\alpha)\widehat{R}_{0,k}$$

- Tends to work quite well

Example filtered resistance



- Filtered resistance quite close to true resistance

Issues (3–4)

ISSUE III: ESR is SOC-dependent

- SOC dependence could be handled by adapting resistance vectors rather than scalars

ISSUE IV: ESR is temperature-dependent

- Temperature dependence can be well modeled as

$$R_0 = R_{0,\text{ref}} \exp\left(E_{R_0,\text{ref}}\left(\frac{1}{T_{\text{ref}}} - \frac{1}{T}\right)\right)$$

  but if pack dwells near one temperature for an extended period, results at other temperatures may become biased
- Can also adapt matrix of resistances vs. SOC and temperature

Summary

- An estimate of equivalent-series resistance R_0 is a component to most SOH estimates
- The good news is that ESR is highly observable: even simple methods can estimate its value well
- You learned a simple—but noisy—approach, based on differencing voltages and currents
  - Filtering these results can produce good ESR estimates
- You also learned some ways to handle SOC- and temperature-dependence