Limits based on SOC, max current and power

- Last lesson, reviewed basic HPPC method for computing estimates of power-limits
- Can quite easily extend method to include SOC-based limits with a time horizon ΔT
- For constant current i_n, SOC recursion is: $z_n(t+\Delta T) = z_n(t) - (\eta_n \Delta T/Q) i_n$
  - Assume $\eta_n = 1$ for discharge, and $\eta_n = \eta \le 1$ for charge currents
- If we have design limits such that $z_{\min} \le z_n(t) \le z_{\max}$ for all cells in the pack, we can compute current i_n to enforce these limits
- Simple algebra gives current limits based on the SOC of each cell

$$i_{\max,n}^{\text{dis,soc}} = \frac{z_n(t) - z_{\min}}{\Delta T/Q} \quad \text{and} \quad i_{\min,n}^{\text{chg,soc}} = \frac{z_n(t) - z_{\max}}{\eta \Delta T/Q}$$

Using confidence bounds

- Side information on SOC-estimate uncertainty (*e.g.*, from xKF) can be used to make power estimates more conservative
- This is done as (assuming here that we desire to use a $3\sigma_z$ confidence interval)

$$i_{\max,n}^{\text{dis,soc}} = \frac{(z_n(t) - 3\sigma_{z,n}) - z_{\min}}{\Delta T/Q}$$

$$i_{\min,n}^{\text{chg,soc}} = \frac{(z_n(t) + 3\sigma_{z,n}) - z_{\max}}{\eta \Delta T/Q}$$

- So, even if estimate of z_n is inaccurate, future SOC will not violate limits if estimate is within $\pm 3\sigma$ bounds

Combining limits

- Once all cell current limits have been calculated, pack discharge currents with all limits enforced are computed as

$$i_{\max}^{\text{dis}} = N_p \min\left(i_{\max}, \min_n i_{\max,n}^{\text{dis,soc}}, \min_n i_{\max,n}^{\text{dis,volt}}\right)$$

  - We are finding the value of current closest to zero among all of the limiting currents based on electronics, future SOCs, future voltages
- Recall that charge current has negative sign, so must use “max” to compute value of current closest to zero

$$i_{\min}^{\text{chg}} = N_p \max\left(i_{\min}, \max_n i_{\min,n}^{\text{chg,soc}}, \max_n i_{\min,n}^{\text{chg,volt}}\right)$$

Computing power

- Pack power is sum of all cell powers, using maximum allowed current and predicted future voltage

$$
\begin{aligned}
P^{\text{chg}}_{\min} &= \max\left(N_s p_{\min}, \sum_{n=1}^{N_s} i^{\text{chg}}_{\min} v_n(t+\Delta T)\right)\\
&\approx \max\left(N_s p_{\min}, \sum_{n=1}^{N_s} i^{\text{chg}}_{\min}\left(\text{OCV}\left(z_n(t) - i^{\text{chg}}_{\min}\frac{\eta\Delta T}{N_p Q}\right) - i^{\text{chg}}_{\min}\frac{R_{\text{chg},\Delta T}}{N_p}\right)\right);\\
P^{\text{dis}}_{\max} &= \min\left(N_s p_{\max}, \sum_{n=1}^{N_s} i^{\text{dis}}_{\max} v_n(t+\Delta T)\right)\\
&\approx \min\left(N_s p_{\max}, \sum_{n=1}^{N_s} i^{\text{dis}}_{\max}\left(\text{OCV}\left(z_n(t) - i^{\text{dis}}_{\max}\frac{\Delta T}{N_p Q}\right) - i^{\text{dis}}_{\max}\frac{R_{\text{dis},\Delta T}}{N_p}\right)\right)
\end{aligned}
$$

Summary

- Previously, computed power based on voltage limits only
- Now, can compute power additionally based on future SOC limits, electronics current limits, load power limits
  - Additionally, can use confidence interval on SOC from xKF to produce conservative estimate of available power
- This completes discussion of the simple HPPC method
- Will next learn how to implement in Octave code