The pack “bar” filter, using ESC model

- Pack-average “bar” filter SPKF estimates following quantities:
  - Pack-average state-of-charge, pack-average diffusion current(s), the pack-average hysteresis voltage
- To implement this SPKF, need a state-space model of pack-average states and how those pack-average states produce a measurable output
  - This lesson will derive pack-average state equation
  - Current-sensor bias state included in model as $i_k^b = i_{k-1}^b + n_{k-1}^b$ where n_k^b is fictitious noise source that is allows SPKF to adapt bias estimate

Example “bar”-filter state equation development

- For example, starting with a single-cell SOC equation

$$
\begin{aligned}
z_k^{(i)} &= z_{k-1}^{(i)} - i_{k-1}\Delta t / Q^{(i)} \\
\frac{1}{N_s}\sum_{i=1}^{N_s} z_k^{(i)} &= \frac{1}{N_s}\sum_{i=1}^{N_s} z_{k-1}^{(i)} - \frac{i_{k-1}\Delta t}{N_s}\sum_{i=1}^{N_s}\frac{1}{Q^{(i)}} = \frac{1}{N_s}\sum_{i=1}^{N_s} z_{k-1}^{(i)} - \frac{i_{k-1}\Delta t}{N_s}\sum_{i=1}^{N_s} Q_{\text{inv}}^{(i)} \\
\bar{z}_k &= \bar{z}_{k-1} - i_{k-1}\Delta t\, \bar{Q}_{\text{inv}}
\end{aligned}
$$

- Note the new concept of “inverse capacity” to make the equations simpler.
  - If we’re estimating all cells’ capacities, then have time-varying quantity $\bar{Q}_{\text{inv},k-1}$
- If we also consider the current-bias state, $\bar{z}_k = \bar{z}_{k-1} - (i_{k-1} - i_{k-1}^b)\Delta t\, \bar{Q}_{\text{inv},k-1}$

“Bar”-filter model state equations

- Dynamics of all pack-average states, parameters:

$$
\begin{aligned}
\bar{z}_k &= \bar{z}_{k-1} - (i_{k-1} - i_{k-1}^b)\Delta t\, \bar{Q}_{\text{inv},k-1} \\
\bar{i}_{R_j,k} &= A_{RC}\bar{i}_{R_j,k} + B_{RC}(i_{k-1} - i_{k-1}^b) \\
A_{h,k} &= \exp\left(-\left|(i_{k-1} - i_{k-1}^b)\gamma\Delta t\, \bar{Q}_{\text{inv},k-1}\right|\right) \\
\bar{h}_k &= A_{h,k}\bar{h}_{k-1} + (1 - A_{h,k})\,\text{sgn}(i_{k-1} - i_{k-1}^b) \\
\bar{R}_{0,k} &= \bar{R}_{0,k-1} + n_{k-1}^{\bar{R}_0} \\
\bar{Q}_{\text{inv},k} &= \bar{Q}_{\text{inv},k-1} + n_{k-1}^{\bar{Q}_{\text{inv}}} \\
i_k^b &= i_{k-1}^b + n_{k-1}^b,
\end{aligned}
$$

where $n_k^{\bar{R}_0}$, $n_k^{\bar{Q}_{\text{inv}}}$ are fictitious noise sources that allow SPKF to adapt parameters

“Bar”-filter model output equation

- Pack bar-filter SPKF uses this model of pack-average states and the measurement equation

$$\bar{y}_k = \text{OCV}(\bar{z}_k) + M\bar{h}_k - \sum_j R_j \bar{i}_{R_j,k} - \bar{R}_{0,k}(i_k - i_k^b) + v_k,$$

where v_k models sensor noise

Summary

- xKF to implement pack-average “bar” filter must have state and measurement equations
- You have learned how to develop these averaged equations, using the SOC equation as an example
- You have also seen one method for parameter adaptation using xKF (there will be more of this in the next course)
- The next step is to see how to implement the “delta” filters