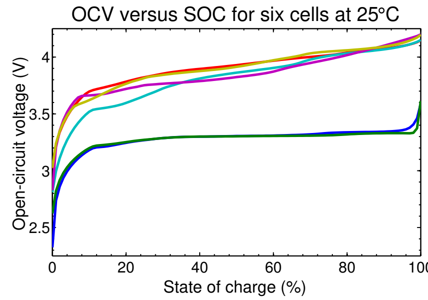
Cell total energy estimate

- Energy is an ability to do work, measured in Wh or kWh
- Cell total energy is equal to

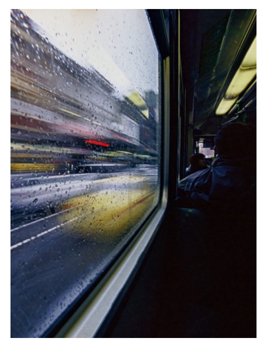
$$E(t) = Q \int_{z_{\text{min}}}^{z(t)} \text{OCV}(\xi)\,\mathrm{d}\xi \approx Q V_{\text{nom}} \Delta z$$

  - ☐ Not a function of temperature or rate
- But, impossible to get all energy out of cell at high rates and cold temperatures
  - ☐ Why we need power estimates as well

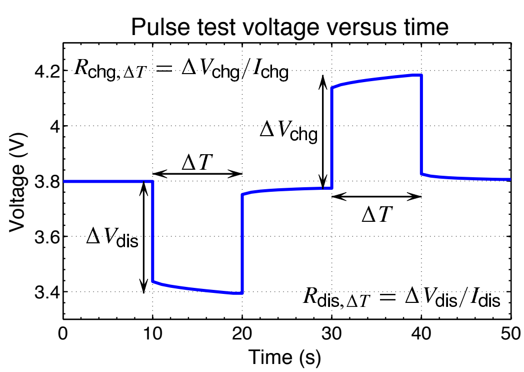


Cell available power estimate

- Power is rate at which can move energy without exceeding cell or electronics design limits
- Dis/charging at too high a power level will accelerate cell degradation and lead to premature battery-pack failure
- Power is instantaneous quantity: $P = IV$ in W or kW
- But, estimate must provide moving-window power limits
  - ☐ Calculate to enforce design limits (*e.g.*, on cell voltage and current), predictive over ΔT second future time horizon
  - ☐ Update at a faster rate than once every ΔT seconds



Cell available power estimate



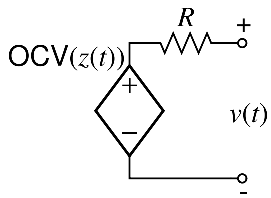
- In course 5, we will explore advanced methods to compute cell power
- In the meantime, we introduce a simple (and commonly used) approach
- Run hybrid pulse power characterization (HPPC) tests; tabulate cell resistance at different SOC and temperature setpoints

HPPC discharge power

- For HPPC discharge power, assume simplified cell model

$$v(t) = \text{OCV}(z(t)) - i(t)R$$

$$i(t) = \frac{\text{OCV}(z(t)) - v(t)}{R}$$



- Assume we're concerned only with keeping voltage between v_{min} and v_{max}
- For discharge power, set $R = R_{\text{dis},\Delta T}$ and clamp $v(t) = v_{\text{min}}$

$$P_{\text{dis}} = v(t)i(t) = v_{\text{min}} \frac{\text{OCV}(z(t)) - v_{\text{min}}}{R_{\text{dis},\Delta T}}$$

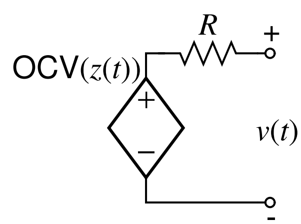
HPPC charge power

- Using same simplified cell model

$$i(t) = \frac{\text{OCV}(z(t)) - v(t)}{R}$$

- For charge power, set $R = R_{\text{chg},\Delta T}$ and $v(t) = v_{\text{max}}$

$$P_{\text{chg}} = v(t)i(t) = v_{\text{max}} \frac{\text{OCV}(z(t)) - v_{\text{max}}}{R_{\text{chg},\Delta T}}$$



- Note that this quantity is negative: Can multiply by -1 (take absolute value) if need to report as positive value
- Usually derate HPPC estimates since the equations assume initial equilibrium condition

Summary

- Cell total energy easily computed using cell SOC z_k, total capacity Q_k, and OCV relationship
- Cell available power is estimated over future moving-window time horizon to avoid damaging cell, electronics
- HPPC method is simple way to characterize cell and estimate power
  - Has limitations, as we will see in course 5, so HPPC computations should be derated in practice

Credits

Credits for photos in this lesson

- Blurry image outside of moving window on slide 2: Pixabay CC0 license (https://pixabay.com/en/service/license/); cropped from https://pixabay.com/en/transport-blurry-moving-tram-bus-2262256/