Estimating Battery Life

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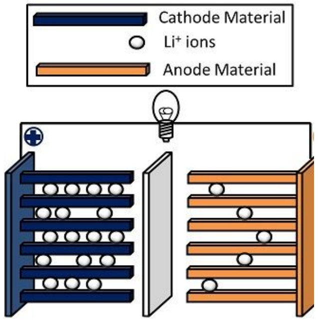
Battery Background Theory

[1]



- Batteries are electrochemical devices
- Focus: Li-Ion batteries
- Li-ions are intercalated between the layers of the carbon anode during charging
- These move through the electrolyte to be intercalated in the cathode during discharge
- The solid-electrolyte interphase (SEI) layer protects the cathode from degradation during operation, but can also trap Li-ions, reducing capacity
- The separator prevents conduction of electrons between the cathode and anode but allows Li-ions to pass

Important Battery Parameters

- Capacity (Ah or Wh)
- Voltage
- Rate capability (C or A)
  - How much current you can draw
  - Charge and discharge may have slightly different rates
- Cycle Life
- Battery chemistry
  - Li-ion batteries: high-power devices
  - NiMH batteries: lower power, less expensive than Li-ion
  - Alkaline batteries: infrequently-used or low-power devices
  - Lead-acid: low cost per Wh, but heavy and damaged by full discharge

Determining Power Requirements

- Determine power requirements for all functional blocks and sum them

Let n be the list of all power-consuming subsystems.

Case 1: subsystem powered directly to battery

$$P_n = I_n \times V_n$$

Case 2: subsystem powered by switching converter with efficiency η

$$P_n = \frac{I_n \times V_n}{\eta}$$

Case 3: subsystem powered by linear regulator with input V_{unreg}

$$P_n = I_n \times V_{unreg}$$

$$\boxed{P_{total} = \sum_{0}^{n} P_n}$$

Estimating Battery Life

$$T_{runtime}[h] = \frac{E_{battery}[Wh]}{P_{total}[W]}$$

$$Allowed\ Capacity\ Loss = \frac{T_{runtime} - T_{runtime(min\,spec.)}}{T_{runtime}} \times 100\,\%$$

- Cross-reference allowed capacity loss with datasheet to determine cycle life
  - Make sure C-rate is close to what you intend to draw
- If you can estimate the number of cycles per year, use the following to get the lifetime in years:

$$T_{life}[years] = \frac{N_{cycles_{life}}}{N_{cycles_{yearly}}}$$

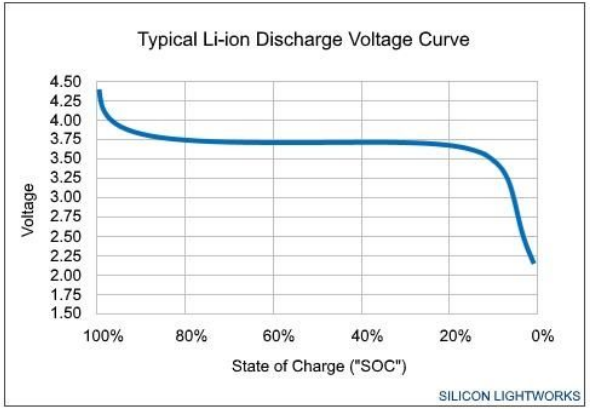
State-of-Health (SoH)

- As a battery ages, it’s SoH decreases
    - Intercalation can damage to the crystal structure of of the anode and cathode over time, decreasing the available spaces for ions
    - Ions may become trapped in the SEI layer
- High discharge and charge rates promote damage
- Discharging a battery fully causes irreversible damage
- Overcharging also damages SoH, and can cause battery rupture and fires
- High temperatures cause electrolyte degradation, which in turn decreases SoH
- To determine the SoH, it is necessary to have a frame of reference for 100 % health to compare the capacity of the battery to

State of Charge (SoC)

- Determining SoC is not just a voltage measurement
  - Battery voltage decreases as charge is depleted, but the relationship is very non-linear
  - The lower the SoC, the lower the voltage drops when placed under load
  - A LUT may be used to compare the current battery voltage to the known curve
- Cold temperatures temporarily decrease the SoC by slowing ionic transport

[2]



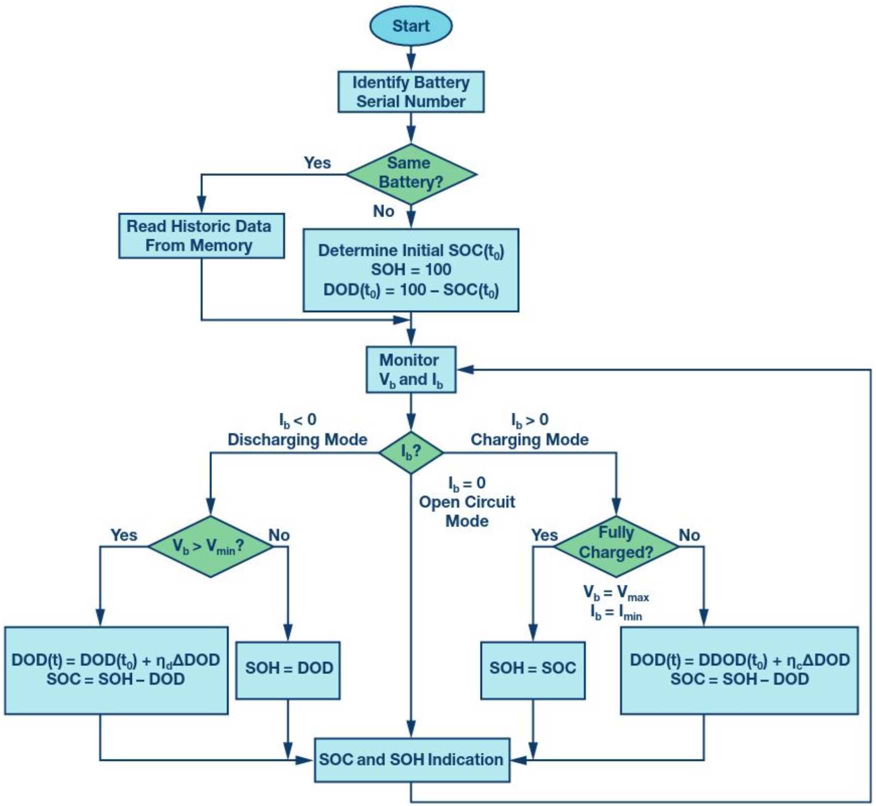
Current-Integration SoC Measurement

- Required: capacity (SoH) is known; the battery management system can measure current and has memory
- Starting at full charge, monitor the battery current and integrate to get utilized capacity [3]

$$SOC = SOC(t_0) + \frac{1}{C_{\mathrm{rated}}} \int_{t_0}^{t_0 + \tau} (I_{\mathrm{b}} - I_{\mathrm{loss}})\, dt$$

- Ideally, should automatically recalibrate for changing SoH
- Integral should reset to zero on full charge; otherwise, drift will occur over time

SoC Estimation Detail [3]



Citations

[1] Materialsgrp, “Schematic of a lithium ion battery,” Wikimedia Commons, 03-Dec-2010. [Online]. Available: https://en.wikipedia.org/wiki/Separator_(electricity)#/media/File:Schematic_of_a_Li-ion_battery.jpg. [Accessed: 23-Jan-2023].

[2] “Typical Li-Ion Discharge Curve,” Silicon Lightworks, LLC, [Online]. Available: https://siliconlightworks.com/li-ion-voltage. [Accessed: 15-Feb-2023].

[3] M. Murnane, A. Ghazel, “A Closer Look at State of Charge (SOC) and State of Health (SOH) Estimation Techniques for Batteries,” Analog Devices, Inc, [Online]. Available: https://www.analog.com/media/en/technical-documentation/technical-articles/a-closer-look-at-state-of-charge-and-state-health-estimation-techniques.pdf