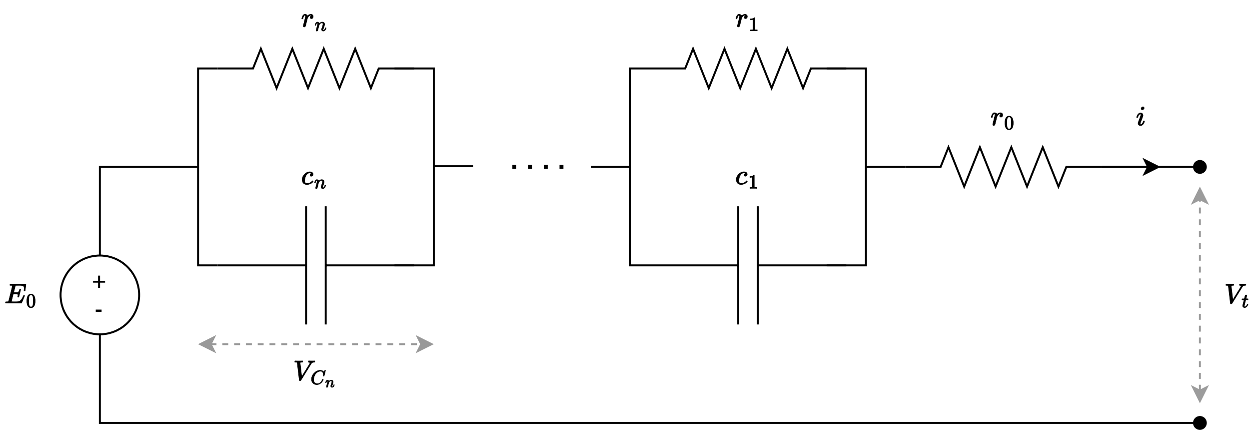
Physics

Schematic



$E_0 \rightarrow open\ circuit\ voltage\ (V)$
$V_t \rightarrow terminal\ voltage\ (V) \leftarrow output\ of\ the\ model$
$i \rightarrow current\ draw\ (A) \leftarrow input\ to\ the\ model$
$r_n, c_n \rightarrow resistance\ and\ capacitances\ (\Omega, F)$

Model equations

Electrical model

$$V_t = E_0 - \sum_{1 \to n} V_{c_n} - ir_0$$

$$\frac{dV_{c_n}}{dt} = \frac{i}{c_n} - \frac{V_{c_n}}{r_n c_n}$$

$$\frac{soc}{dt} = \frac{-i}{Q_{Ah} \times 3600}$$

Thermal model

$$P_{heatGen} = i^2 r_0 + \sum_{1 \to n} \frac{V_{c_n}^2}{r_n}$$

$$P_{heatOut} =$$

BMS

SOC estimation (real time)

1. Direct methods
    1. CC (Coulomb couting)
    2. ECC (Enhanced CC)
2. Model-based methods
    1. Kalman filtering
3. Data-driven methods

Define SOC

SOC is the ratio of the present charge content of the cell to the maximum possible charge content at a pre-defined temperature and C-rate

$$SOC = \frac{Q_{remaining}}{Q_{max}} \times 100\ \%$$

Direct methods

Coulomb counting (CC)

In this method, the SOC of a cell (battery) is estimated by counting the amount of charge (coulombs) entering or leaving the battery

$$SOC(t) = SOC(t_0) + \frac{1}{Q_{max_{As}}} \int_0^T idt \times 100\ \%$$

Problems

- strong dependence of initial value of SOC
- requires high precision current measurement
- does not consider health of the battery (unless $Q_{max_{As}}$ is calibrated)

Enhance coulomb counting (ECC)

This follows the crux of couting charge, but adds corrections in terms of:

- reseting battery SOC from SOC-OCV table as it rests beyond its largest time constant (this solves the initial SOC value problem with CC)
- adding correction terms like discharge efficiency and Peukert equation coefficient and generic current-based polynomial to the term that is integrated (this solves the lack of precision with current integration)
- the additional coefficients ($\eta_{coulumb}$, k, n, a_n) are tuned from repeated power draw $\leftrightarrow$ rest cycles with SOC-OCV resets baked in between the cycles

$$SOC(t) = SOC(t_0) + \frac{\eta_{coulomb}}{Q_{max_{As}}} \int_0^T [i^k + \sum_0^n (a_n i^n)]\ dt \times 100\ \%$$

- this method works for a particular power draw cycle

Note: OCV measurement and EIS can be used to estimate SOCs for non-real-time applications

Model-based methods

A big maybe $\rightarrow$ The main idea is to use a model to predict OCV from measurements like current and voltage, and then use the OCV to lookup SOC from the OCV-SOC relationship