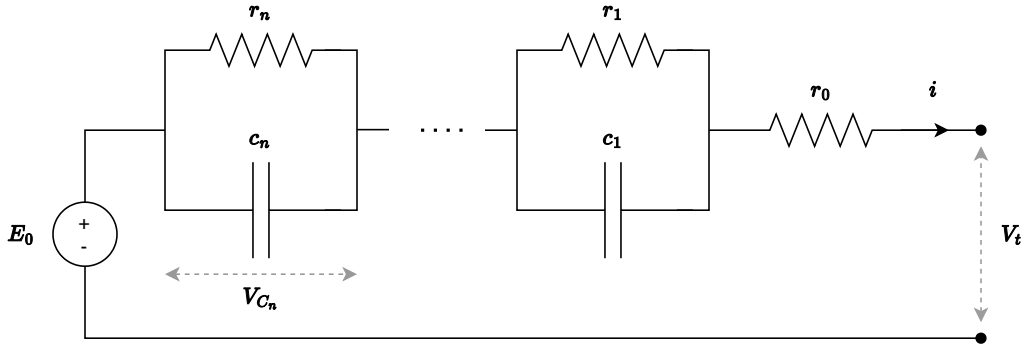


Physics

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 (Ω, F)

Model equations

Electrical model

$$V_t = E_0 - \sum_{1 \rightarrow n} V_{c_n} - i r_0$$

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

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

Thermal model

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

$$P_{heatOut} =$$

BMS

SOC estimation (real time)

1. Direct methods
 - i. CC (Coulomb counting)
 - ii. ECC (Enhanced CC)
2. Model-based methods
 - i. ECM observer models
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

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

Problems

- 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 counting charge, but adds corrections in terms of:

- resetting battery SOC from SOC-OCV table as it rests beyond its largest time constant
- adding correction terms like discharge efficiency and Peukert equations to the term that is integrated
- the additional coefficients ($\eta_{coulomb}$, 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 set of power draw cycle

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

Model-based methods