Estimation of Battery Parameters and SOC: Method and Smart Grid Applications

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Topics

- Introduction
- Joint Estimation of Battery Parameter and SOC
- Algorithm Verification
- Applications

Challenges in Parameter and SOC Estimation

- Nonlinear and time-varying dynamics: SOC, SOH (remaining life), model parameters vary as
  - Aging
  - Changes in operational conditions
  - Chemical property variations
- Expensive sensors, non-measurable signals
- Flat voltage curves
- Noise in measurement
- Capture dynamics in real time

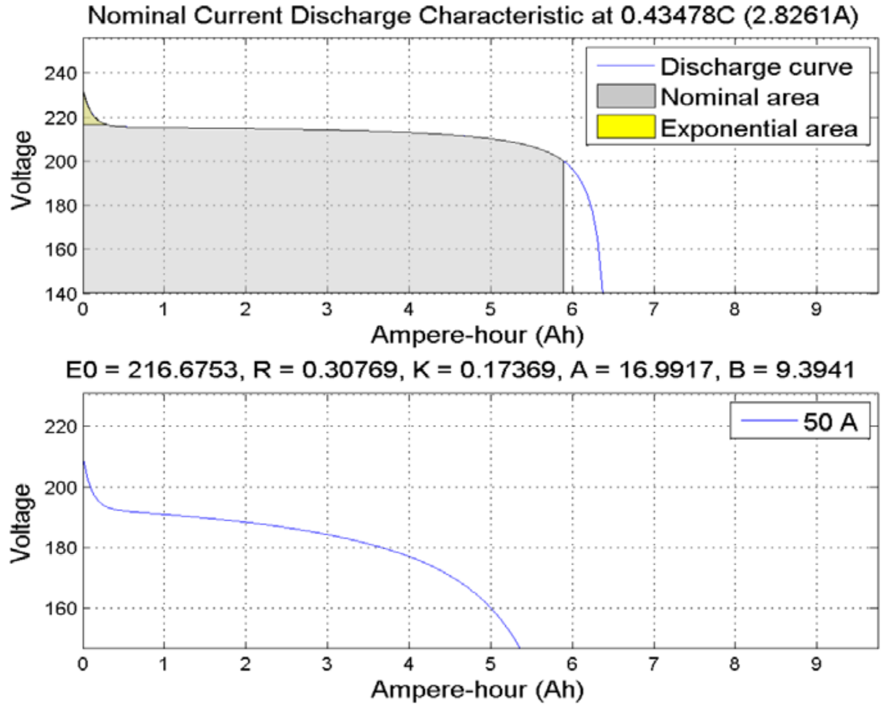
Joint Estimation – Output Re-formation

$$
\begin{aligned}
v(t) &= E_0 - K\frac{Q(1-s(t))}{s(t)} - K\frac{i(t)}{s(t)} - Ri(t) \\
&= E_0 + KQ - \frac{KQ}{s_0 - \frac{1}{Q}\lambda(t)} - \left(\frac{K}{s_0 - \frac{1}{Q}\lambda(t)} + R\right) i \\
&= h(t) - g(t)i(t)
\end{aligned}
$$

$$h(t) = E_0 + KQ - \frac{KQ}{s_0 - \frac{1}{Q}\lambda(t)}$$

$$g(t) = \frac{K}{s_0 - \frac{1}{Q}\lambda(t)} + R$$

$$\lambda(t) = \frac{1}{3600}\int_{t_0}^{t} i(\tau)d\tau$$



Parameters to be estimated: E_0, K, Q,

State to be estimated: s_0

Joint Estimation – Statistical Property

Add an sequence $\{\varepsilon_k : k = 1, \ldots, N\}$ of mean zero and variance σ^2 in a small interval $(t - \tau, t]$ on the input current

By the strong law of large numbers, the sample average of $v(\tau_k)$ converges strongly

$$\mu_N = \frac{1}{N}\sum_{k=1}^{N} v(\tau_k) \to h(t) - g(t)i(t), N \to \infty, w.p.1$$

Sample variance converges strongly

$$\delta_N = \frac{1}{N-1}\sum_{k=1}^{N}(v(\tau_k) - \mu_N)^2 \to \sigma^2(g(t))^2, N \to \infty, w.p.1$$

Estimate for

$$\widehat{g}_N(t) = \sqrt{\delta_N/\sigma^2} \qquad \widehat{g}_N(t) \to g(t), N \to \infty, w.p.1.$$

$$\widehat{h}_N(t) = \mu_N + \widehat{g}_N(t)i(t) \qquad \widehat{h}_N(t) \to h(t), N \to \infty, w.p.1.$$

Joint Estimation

For the identified values of $h(t)$ and $g(t)$ at t_j , j = 1, . . . ,m.

$$g(t_j) = \frac{K}{s_0 - \frac{1}{Q}\lambda(t_j)} + R$$

$$h(t_j) = E_0 + KQ - \frac{KQ}{s_0 - \frac{1}{Q}\lambda(t_j)}$$

$$\theta = [R, K, E_0, Q, S_0]'$$

$$\hat{\theta} = [\hat{R}, \hat{K}, \hat{E}_0, \hat{Q}, \hat{S}_0]'$$

$$F(\theta) = \begin{bmatrix} \frac{K}{s_0 - \frac{1}{Q}\lambda(t_1)} + R \\ \vdots \\ \frac{K}{s_0 - \frac{1}{Q}\lambda(t_m)} + R \\ E_0 + KQ - \frac{KQ}{s_0 - \frac{1}{Q}\lambda(t_1)} \\ \vdots \\ E_0 + KQ - \frac{KQ}{s_0 - \frac{1}{Q}\lambda(t_m)} \end{bmatrix} ; H = \begin{bmatrix} g(t_1) \\ \vdots \\ g(t_m) \\ h(t_1) \\ \vdots \\ h(t_m) \end{bmatrix}$$

$$\hat{\theta}_{k+1} = \hat{\theta}_k + \varepsilon_k (J(\hat{\theta}_k)' J(\hat{\theta}_k))^{-1} J(\hat{\theta}_k)'(H - F(\hat{\theta}_k))$$

Joint Estimation - Simulation Results

For m = 33 steps:

$$\lambda(t_1) = 0.03Q, \lambda(t_2) = 0.04Q, \ldots, \lambda(t_{33}) = 0.35Q$$

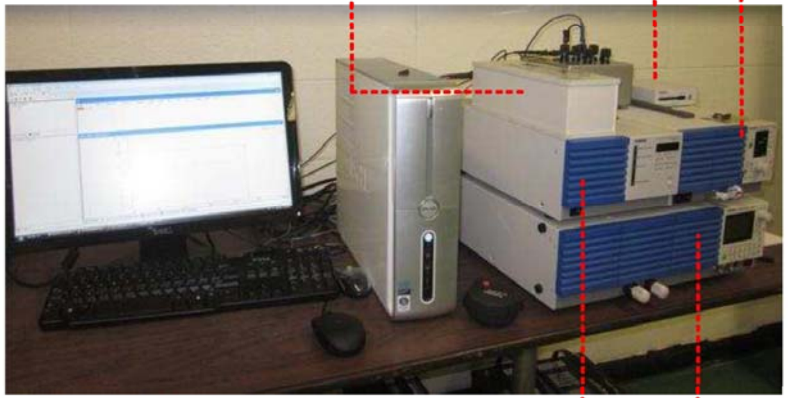
$$\|(J(\theta)' J(\theta))^{-1}\| = 115.2$$ Full rank, well conditioned!

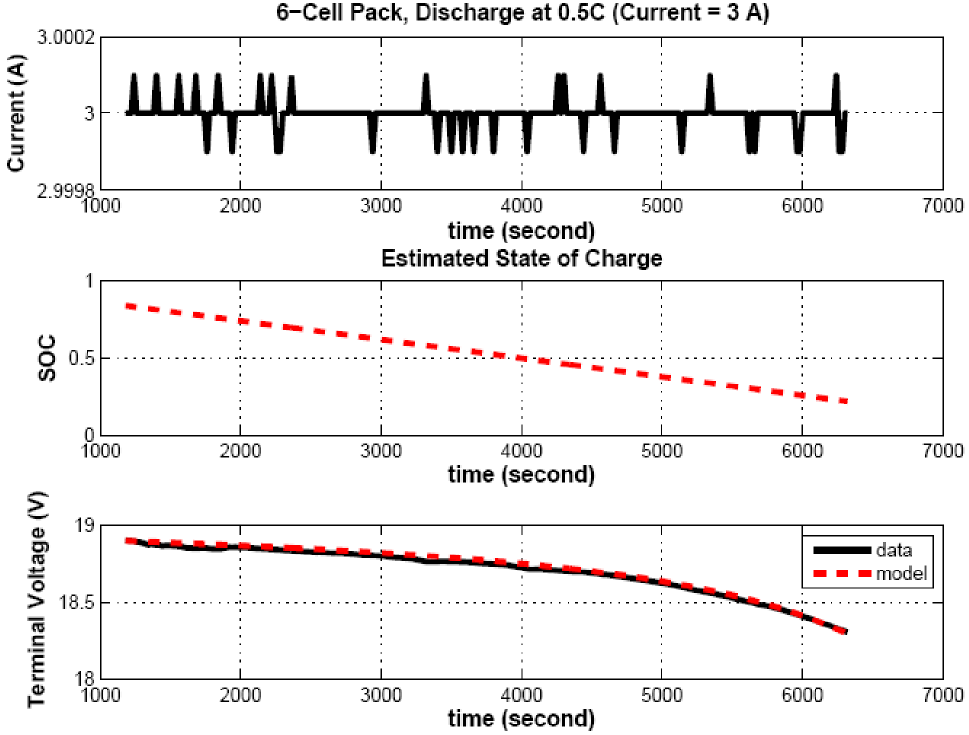
$$\hat{\theta}_0 = [0.2, 0.1, 205, 6, 0.65]'$$

$$\hat{\theta}_{150} = [0.3353, 0.1631, 216, 5810, 6.4595, 0.834]'$$

$$\theta_a = [0.3077, 0.1737, 216, 6753, 6.5, 0.8]'$$

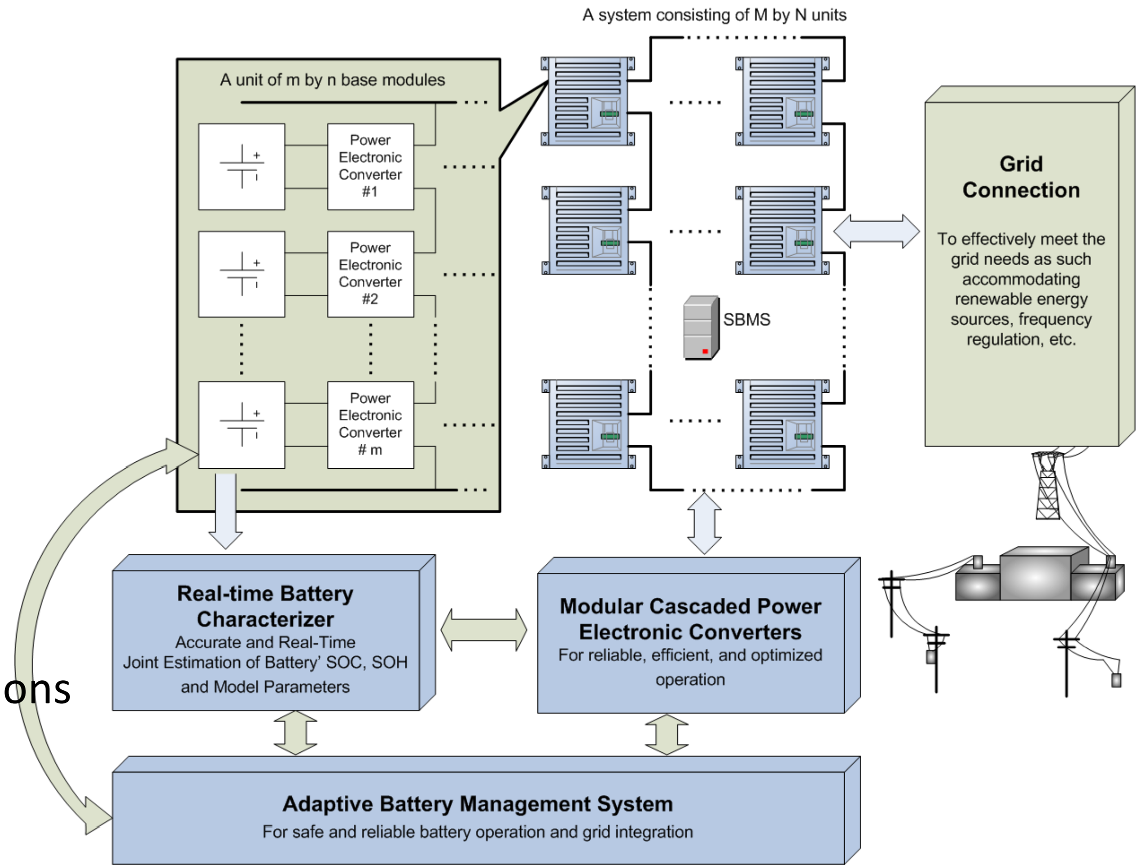
Algorithm Verification





Applications

- Battery Management Systems
- Optimal Battery Charging/Discharging Controllers
- Real-time Battery Characterizer
- Stationary grid applications using retired batteries
- …



SOC Weighted Control for Grid Battery Storage System