# Model-based Online Estimation of the State of Charge in Lithium-ion Batteries

C. Brivio, R. E. Carrillo, P.-J. Alet

*Everyone has seen the remaining charge on their mobile phone drop near instantly from 15% to zero. CSEM is developing a novel state of charge (SoC) estimator under the BESTIMATOR project. This algorithm improves the state of the art through: (i) a robust approach based on an electrical model developed at CSEM in the past few years; (ii) the mathematical processing to derive the SoC from the measurements at the battery terminals. First tests on real measurements show that our estimator achieves a maximum SoC estimation error of 3% and beats both the common Coulomb counting and advanced methods from industry leaders. The Bestimator™ algorithm can be implemented in battery management systems (BMS) for online SoC estimation in a broad range of applications including electric vehicles and grid services.*

The Bestimator™ SoC estimation algorithm developed at CSEM comprises two main parts (see Figure 1). The first part is the physics-based lithium-ion model developed at CSEM[1] that accounts for the nonlinearities of Li-ion cells with respect to current and SoC levels. The novelty of our approach lies in the clear link between the equations describing the electrochemical phenomena in the battery, and the impedance blocks in the model. Its development used electrochemical impedance spectroscopy (EIS) and open circuit voltage (OCV) measurements, and the model was validated on lithium nickel oxide cells. The accurate battery model makes Bestimator™ highly reliable in simulating the correct behavior of the cell.

The second part of the algorithm is an extended Kalman filter which estimates the SoC based on the voltage and current levels at the battery terminals. It operates in three stages: parts: (i) predicting OCV and the voltage drops across the impedance blocks of the battery model; (ii) correcting the OCV and voltage drops based on the error between the estimated and measured terminal voltage values; (iii) deriving the SoC from the estimated OCV with an OCV-SoC relationship derived from the cell model.

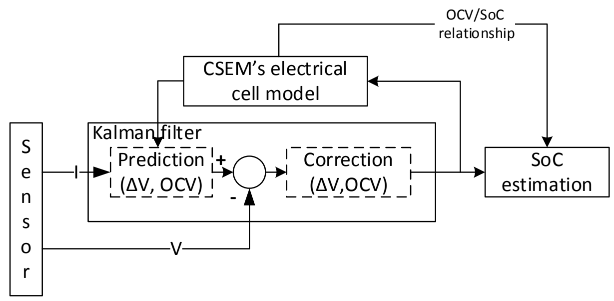


*Figure 1: Block diagram of CSEM's Bestimator™ algorithm.*

We have compared Bestimator™ with two other methodologies which represent the state of the art:

- Coulomb counting algorithm, which simply computes the integral of the current over time and updates the SoC with respect to the nominal capacity of the battery cell. Coulomb counting is very sensitive to initial conditions and prone to deviating over longer estimation time.
- Panasonic patent application EP 3115797 (A1)[2], which uses a Kalman filter to correct the error from the Coulomb counting SoC estimation. It uses a simplified electrical battery model to compare the measured voltage with the predicted one at the estimated SoC.

All methods struggle at extreme values of SoC (below 20% and above 80%, not shown here). While Bestimator™ is satisfactory above 80%, current efforts are focused on improving the method for the 0%-20% SoC region.

Figure 2 shows a comparison of the performance of the three algorithms in a demanding application: grid-connected battery storage for primary control reserve. The fluctuating current profile leads to periodic changes in the cell voltage. Both the Panasonic approach and Bestimator™ succeed in reproducing the measured voltage thanks to the Kalman filters corrections. Coulomb counting has the lowest estimation error of the three methods at the beginning due to the known initial condition however it drifts over time. Indeed, since it is an integral-based methods it accumulates the error if not re-initialized. After only 20 days its error level is the highest. The Panasonic approach starts with the highest error then gradually corrects the error and outperforms plain Coulomb counting after 15 days. Bestimator™ consistently outperforms both methods over the whole time range and achieves a maximum error of 3%.

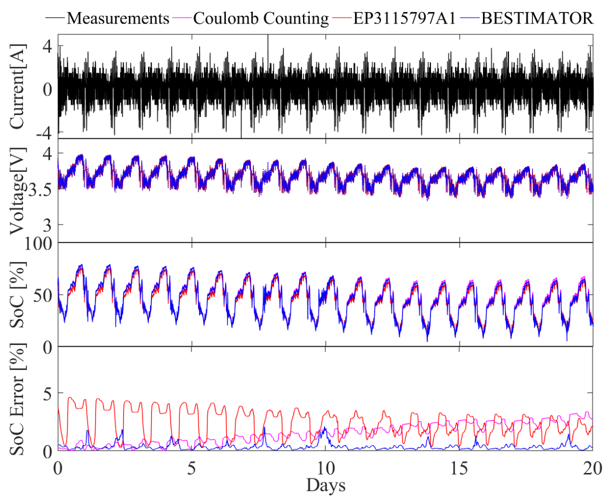


*Figure 2: Comparison of estimates from the Bestimator™ algorithm, Coulomb counting, and the Panasonic method with measured values on a Boston Power Swing 5300 Li-ion cell for 20 days.*

*The BESTIMATOR project is co-funded by Innosuisse under project number 28008.1 PFNM-NM.*

[1] C. Brivio, V. Musolino, M. Merlo, C. Ballif, "A physically-based electrical model for lithium-ion cells", IEEE transactions on energy conversion, 2018 [Accepted].

[2] T. Omi, K. Miura, S. Hiwa, T. Iida, K. Kakutani, "Battery state estimation device and method of estimating battery state", EP3115797 (A1), 11-Jan-2017.