Sandia National Laboratories

DISTURBANCE DETECTION WITH MODELING: FITTING AN ACCURATE EQUIVALENT CIRCUIT MODEL

Victoria O'Brien[1](vaobrie@sandia.gov), Yuliya Preger[1], Rodrigo Trevizan[1], Armando Montoya[1]
[1]*Sandia National Laboratories*

PROJECT PROFILE

Power Electronics | Grid Integration and Field Validation
Strategic Pathway: Stabilize and Optimize
Project start and finish: FY26

PROBLEM

It is challenging to operate battery energy storage systems (BESSs) optimally and to monitor BESSs for disturbances

- Existing controllers and models have varying levels of accuracy
- Existing fault monitoring methods (i.e. chi-squared test) have false alarms and are not designed to detect stealthy cyberattacks
- BESS cybersecurity is often an afterthought or is neglected entirely

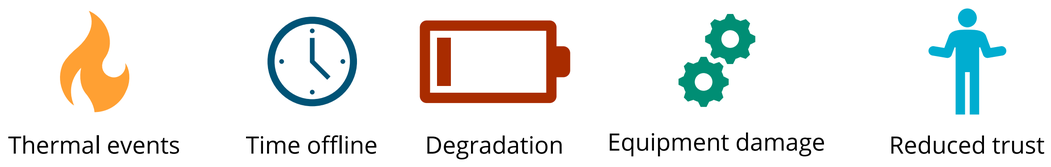

Fig. 1. Possible consequences of BESS failure

Utilities and industry urgently need an **affordable** solution to improve the **safety**, **security**, and **reliability** of BESSs

APPROACH

Accurate battery models improve control systems and can be repurposed to flag disturbances and cyberattacks [1]

- **Battery model:** equivalent circuit model (ECM)
- **State of charge (SoC):** Coulomb counting (CC)
- **Open circuit voltage (OCV):** extracted experimentally
- **Parameter fitting:** sequential least squares programming (SLSQP)

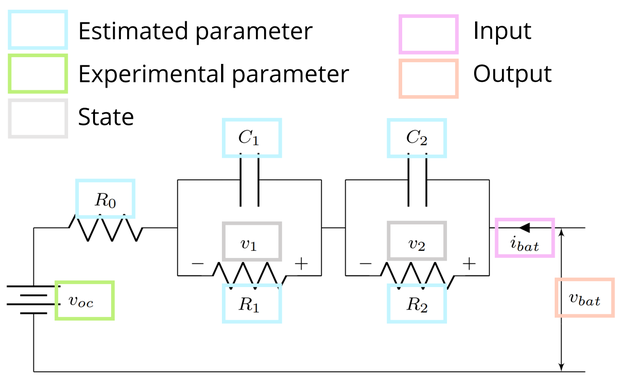

Fig. 2. ECM diagram

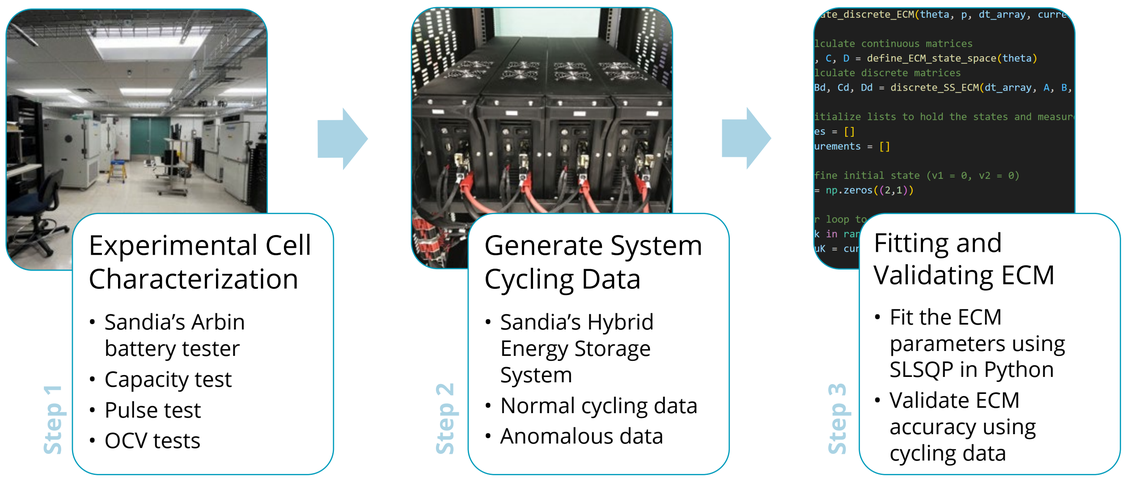

Fig. 3. Battery modeling approach at Sandia

RESULTS

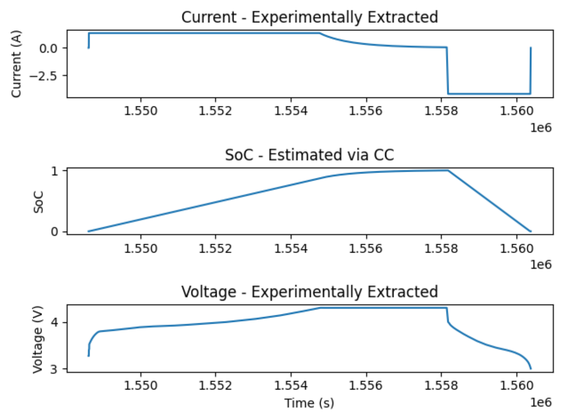

Fig. 4. Cycle 1 current, SoC, and voltage

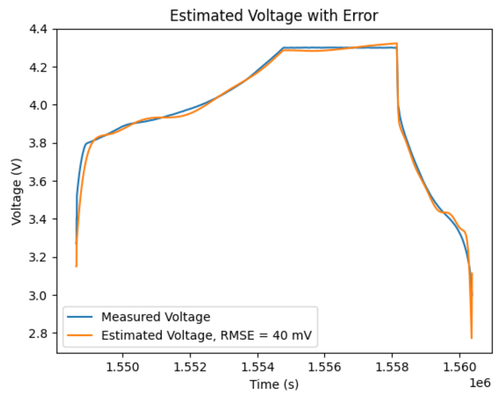

Fig. 5. Cycle 1 estimated voltage

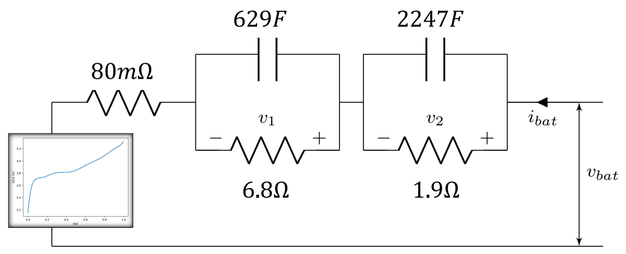

Fig. 6. Cycle 1 optimized ECM parameters

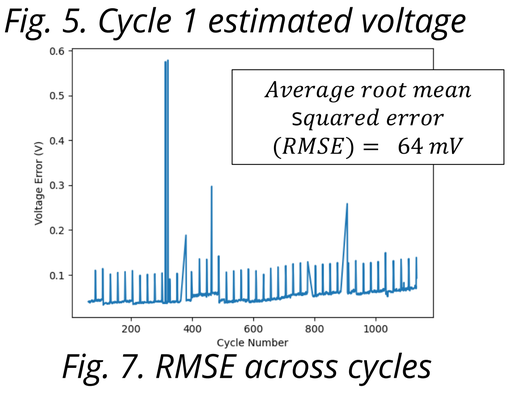

Fig. 7. RMSE across cycles

CONCLUSIONS & IMPACT

The ECM accurately represented a Lithium-ion battery cell's dynamics, as validated by experimental data from [3]

- ECM remained accurate despite degradation
- Parameters were optimized over time to ensure fit
- Method was compatible with multiple cell chemistries

Impacts

Affordability: does not require additional hardware or communications, model may be calibrated for existing systems
Safety and security: protects critical control electronics, which make up 30% of BESS costs [2], by alerting operator of disturbances
Technology transfer: expected after successful proof-of-concept
Compatibility: can be integrated with other Sandia projects, designed as a drop-in solution for the energy management system
Knowledge sharing: several publications are in preparation

FUTURE DIRECTIONS

Use accurate ECM for **anomaly** and **cyberattack** monitoring by [1]:

1. Incorporate a filter/estimator to estimate voltage
2. Compare voltage estimates to measured voltage from BESS
3. Use detector (Fig. 8) on voltage data to flag anomalies and cyberattacks

Low-cost solution enhances **safety** and **security** for BESSs and the grid

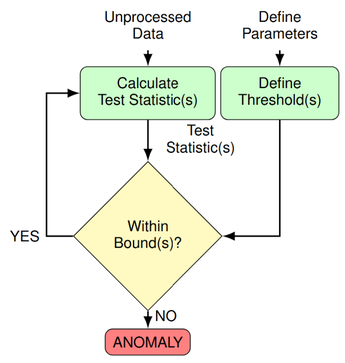

Fig. 8. Anomaly detector

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References

[1] V. A. O'Brien and R. D. Trevizan, "Scaling Up Online Model-Based Anomaly Detection Methods for Use in Large Battery Stacks: Addressing Challenges in Online Monitoring of Battery Systems," in IEEE Industry Applications Magazine, vol. 32, no. 3, pp. 42-55, May-June 2026
[2] M. Worry, "NAATBatt Cybersecurity Committee Plan," presented to NAATBatt Cybersecurity Committee, Virtual, Mar. 19, 2026. [PowerPoint Slides.] Accessed: Mar. 19, 2026.
[3] A. Devie, G. Baure, and M. Dubarry, "Intrinsic Variability in the Degradation of a Batch of Commercial 18650 Lithium-Ion Cells," in *Energies*, vol. 11, no. 5, Apr. 2018.