Multi-Sensor Battery Thermal Runaway Detection based on Voltage, Force and Gas Sensors

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Thanks to
DOE (ARPA-E), U.S. ARMY (TARDEC), NSF, NIST
A123, Amphenol, Navitas, Ford, Samsung, and GE

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Battery Thermal Runaway

Typical features of a battery thermal runaway

- Voltage drops to zero (eventually)
- Temperature rise

Commonly used for thermal runaway detection

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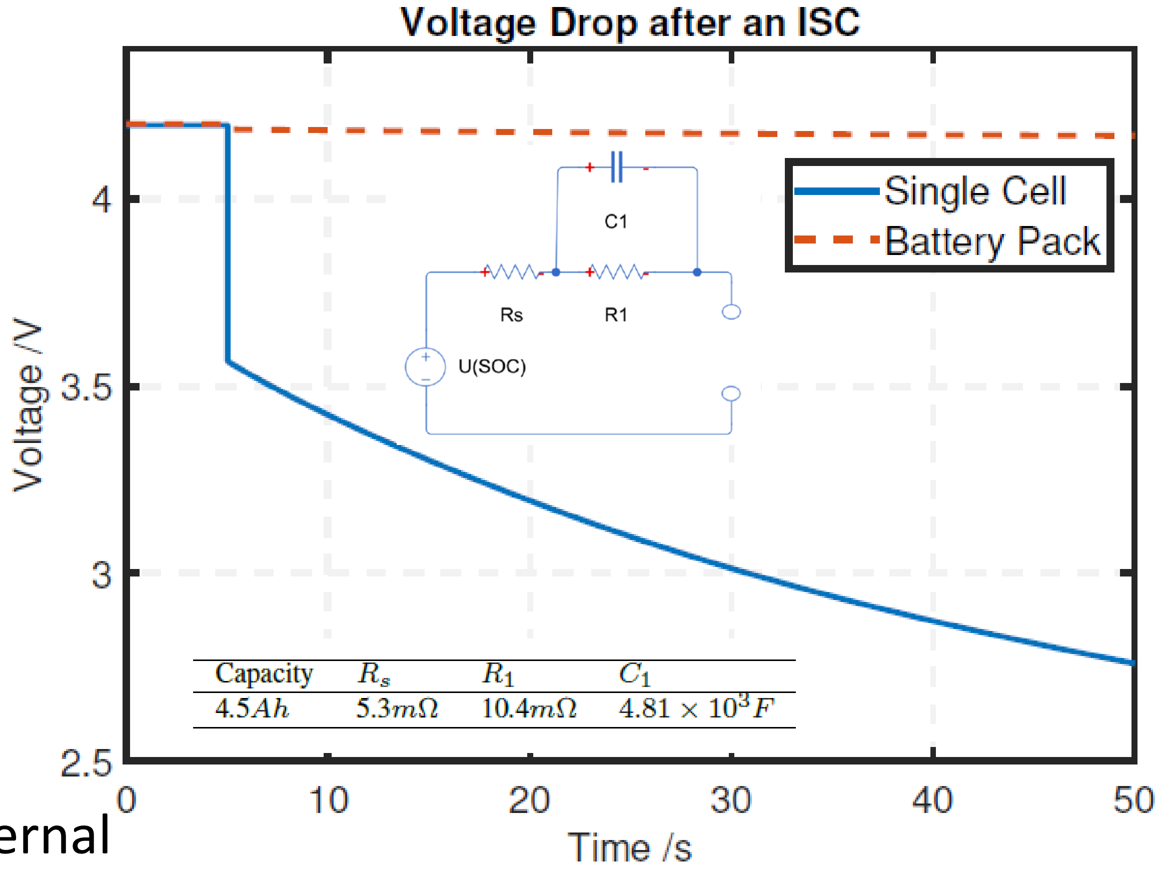
Limitations for Detection of Thermal Runaway

For a battery pack with 50 cells in parallel, voltage-based and temperature-based detection methods encounter difficulty.

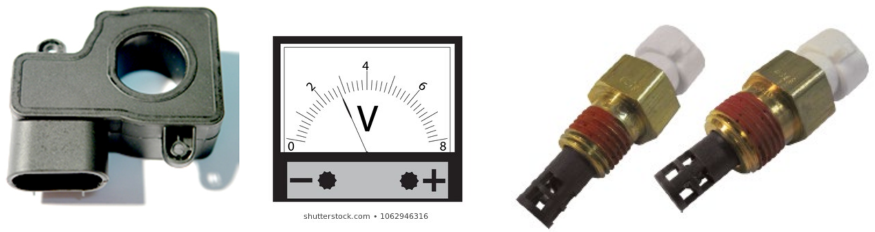
50 cells in parallel



In large battery packs, it is difficult to detect an internal short by voltage or temperature (not all cells are instrumented)!

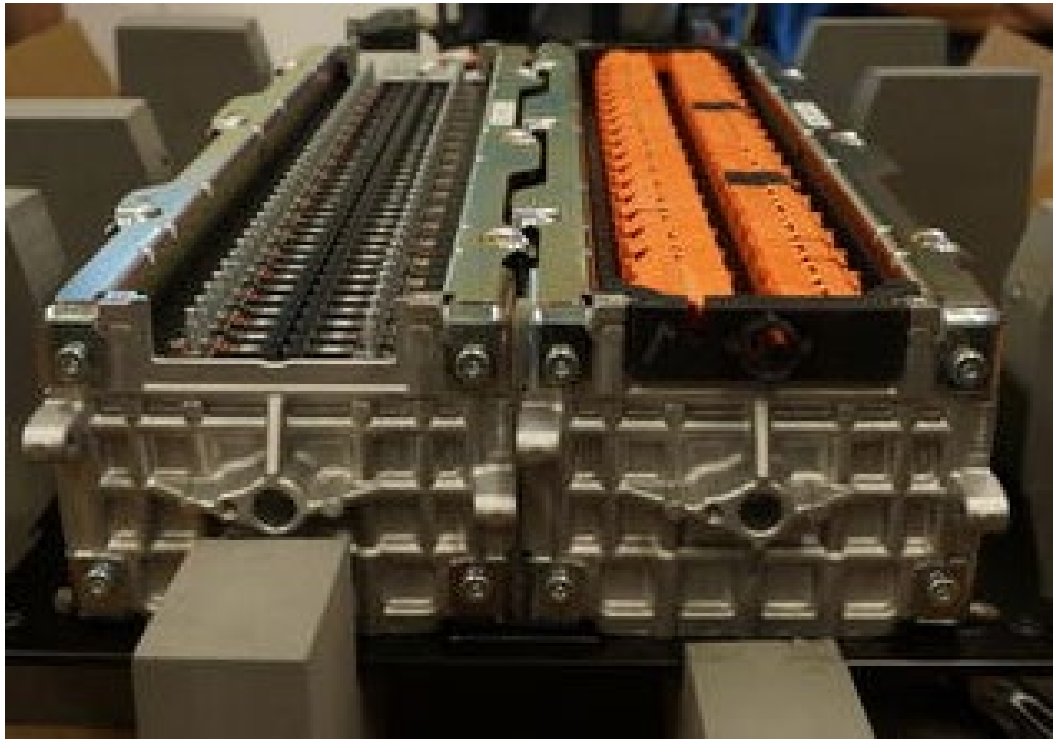
Cai, T., et al, "Battery Internal Short Detection Methodology Using Cell Swelling Measurements", 2020 American Control Conference (Under Review)

Consider a Multi-Sensor Approach (I,V,T,F/P,G)



Current, Voltage, Temperature

CO2 gas concentration



Cell Swelling Force

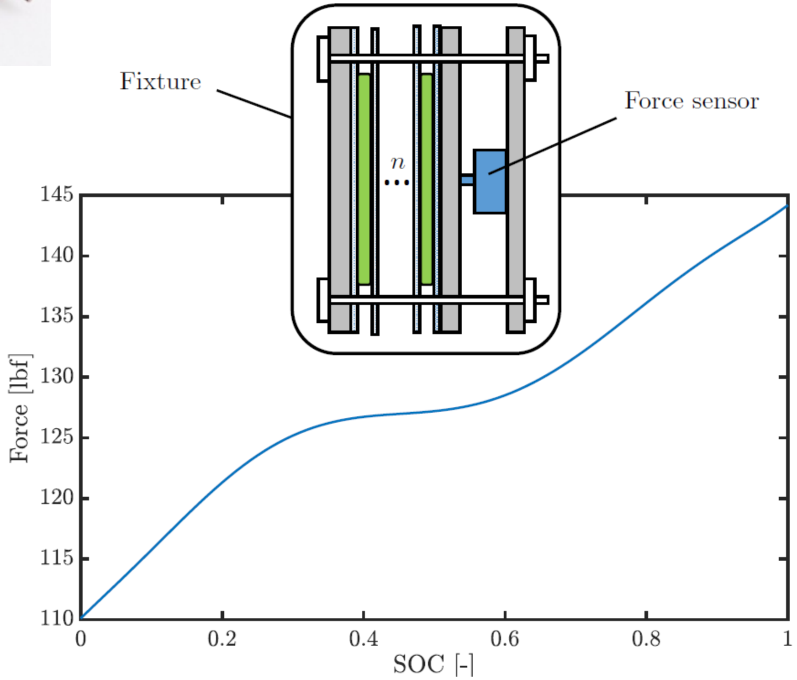
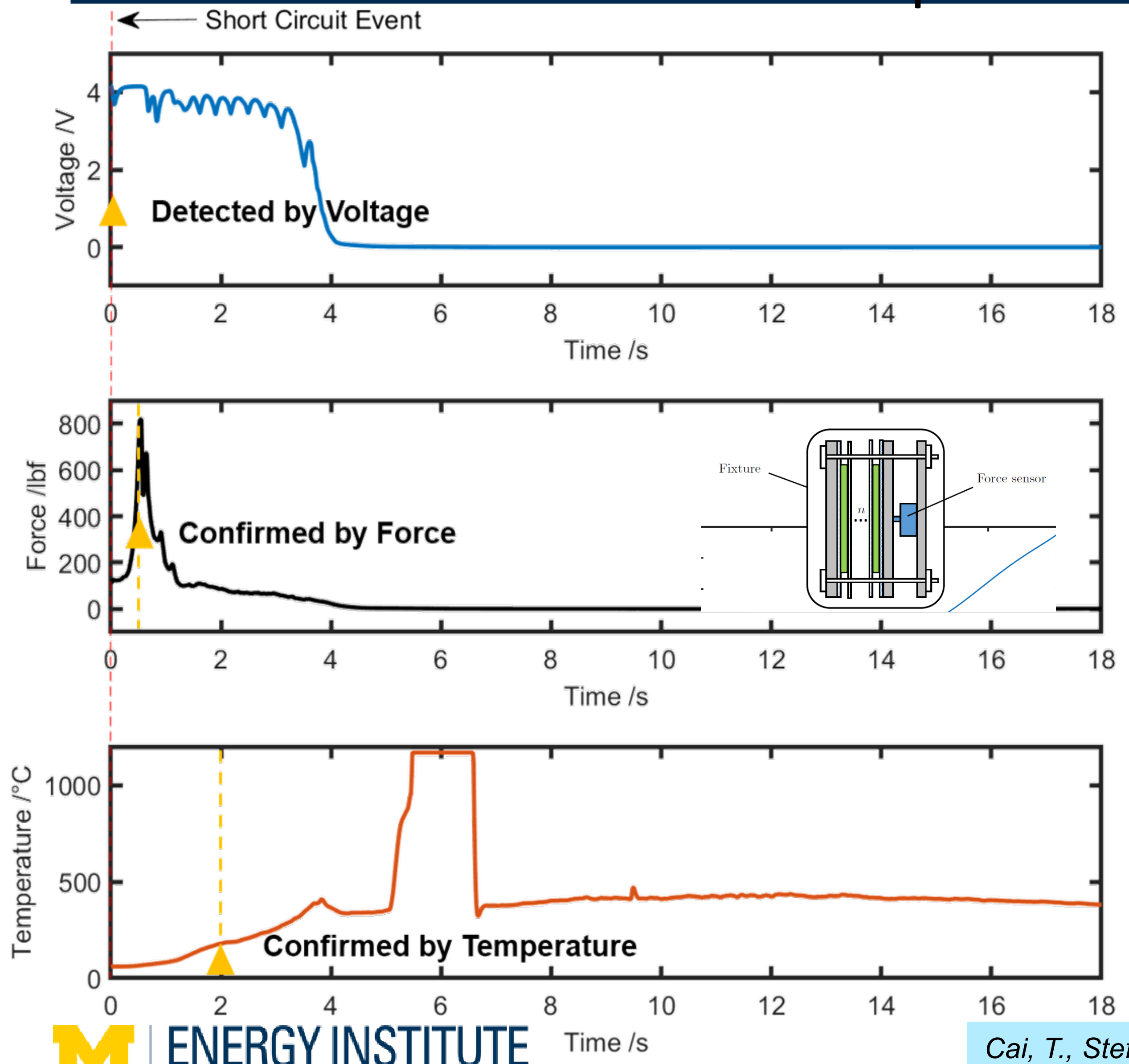


Fig. 2. Expansion force as a function of SOC, for NMC prismatic pouch 4.5 Ah cell at 25°C, with the schematic of the force sensor placement in a pack ($1\ lbf = 4.45\ N$).

Detection with Multiple Sensors (Experimental)



Internal Short Circuit (ISC) experiments

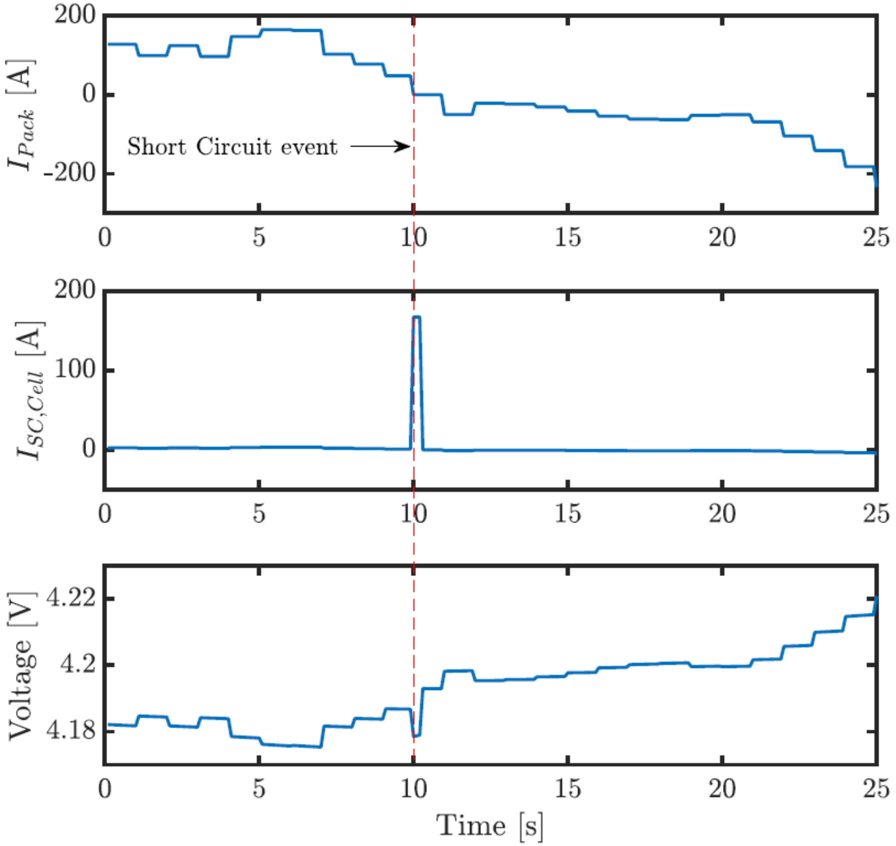
- Wax-based ISC device configured to short at 58 deg C.
- Voltage and force have faster responses than surface temperature.
- Measured force is the result of gas generation that caused cell swelling and rupture.
- Gas detection can be used once the cell vents (indicated by sharp drop in force).

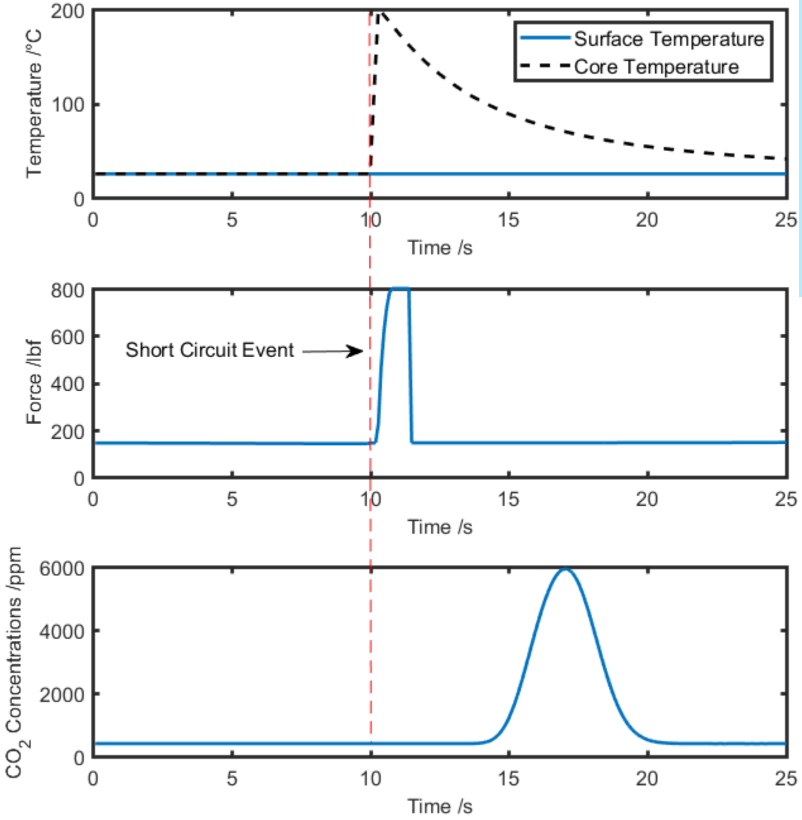
Cai, T., Stefanopoulou, A.G., Siegel, J.B., "Modeling Li-ion Battery Temperature and Expansion Force During the Early Stages of Thermal Runaway Triggered by Internal Shorts", 2019 Journal of Electrochemical Society.

Models Reduce Calibration Effort and Improve Detection

Simulation for an ISC event in a battery pack that does not lead to thermal runaway

- Early detection is critical for scaling back the load power and applying aggressive cooling if TR can be avoided.





Physics based models of **heat** and **gas** generation due to SEI **decomposition** and Thermal Runaway describe pressure buildup and venting.

Gas Sensor Response: Lag due to mass transport (diffusion and convection) Sensor placement is key!

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Cai, T., et al, "Li-ion Battery Fault Detection in Large Packs Using Force and Gas Sensors", 2020 International Federation of Automatic Control (In Review)

Conclusions

Are Battery Management Systems Ready to Tackle Safety?

1) We need multiple sensors for detection
2) We Should integrate Models and Data (Simulation and Sensors)

<u>Beware of Virtual Sensors!!</u>

You need real sensors and on line parameterization when you want to push performance to the edge!

Thanks To: Ting Cai, Sravan Pannala, Mingxuan Zhang, Greg Less (UM), Aaron Knobloch (GE), Brian Engle (Amphenol) National Science Foundation Division of Civil, Mechanical and Manufacturing Innovation

BATTERY LAB

WHAT DOES THE FACILITY DO?

The Battery Lab is an open user facility designed to allow researchers from academia and industry to work with experts in a state-of-the-art lab environment. We create and characterize coin cells, 18650 and 5Ah prismatic pouch cells on equipment that accurately replicates an industrial production environment. The facility meets a defined industry need for pilot scale battery fabrication, characterization and testing for grid storage, transportation, and consumer–product applications.

WHAT CAN THE BATTERY LAB OFFER?

Our facility provides critical infrastructure for the characterization, scale-up, and testing of existing and next-generation energy storage materials and devices. The facility creates new capabilities for in–situ characterization of battery materials and devices under working conditions. This infrastructure investment is key to achieving the breakthroughs needed to make both electric vehicles and grid storage viable at the scales needed for the future. Battery Lab users maintain complete privacy and control of their intellectual property.

WHO ARE THE FACILITY PARTNERS?

The Battery Fabrication and Characterization User Facility has been funded with generous support from Ford Motor Company and the Michigan Economic Development Corporation, and the University of Michigan. The Battery Lab is an important base for University of Michigan energy storage R&D. The facility supports the Joint Center for Energy Storage Research (JCESR), vehicle electrification R&D programs, and ARPA-E-funded research on solid state batteries.

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