# Coupled Electro-thermo Battery Emulator

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## Background

- Lithium batteries, if used aggressively, can combust into an uncontrollable fire called thermal runaway.
- Commercial battery emulators consider the electrical and not thermal characteristics of a lithium-ion battery.

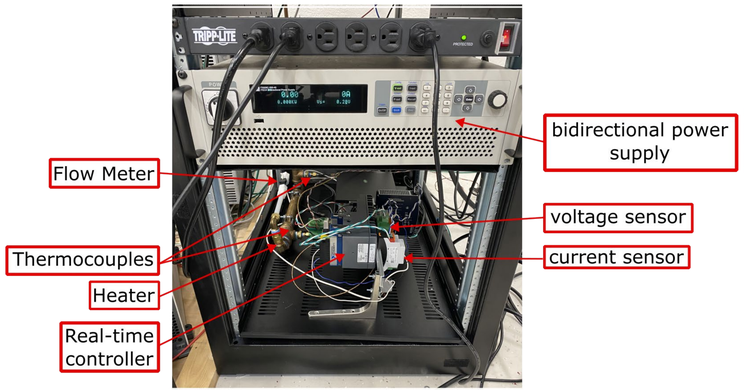
Fleet of buses while charging in China 2021 [1].

Tesla Megapack in Australia 2021 [2].

## Key Points

- Proposed battery emulator can couples the electrical and thermal characteristics of a lithium-ion battery.
- Thermal characteristics are physically emulated to allow for development of cooling methods in powertrains shared cooling systems for power electronics and batteries.
- The electrical characteristics are physically emulated to safely investigate how the battery will electrically affect a system when thermally and electrically stressed.
- Experimental data can be taken from a single cell and then scaled to match any size battery pack to be emulated.

## Design



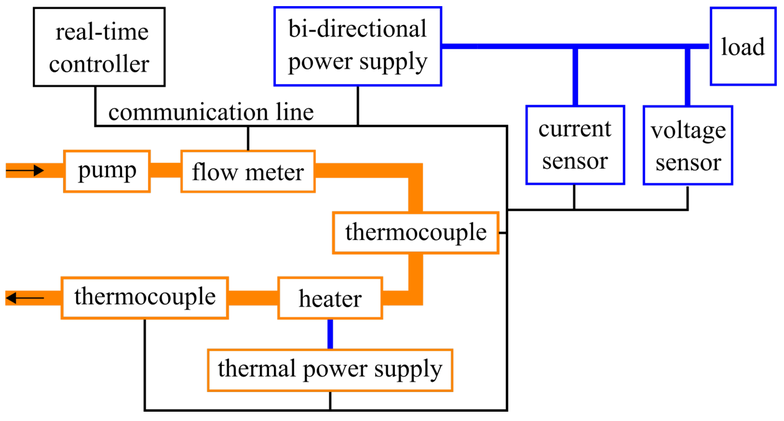

Physical hardware setup of the emulator at USC.

- The battery emulator makes use of a real-time controller with a coupled electrical and thermal domain Simulink model.
- Parameters for the electrical and heat generation model were found through hybrid pulse power testing and organized into look up tables dependent on SoC and temperature.
- Electrical model:

$$V_{\text{out}}(t) = OCV(SoC,T) - i(t_0)R_{\text{ESR}}(SoC,T)$$

- Heat generation model:

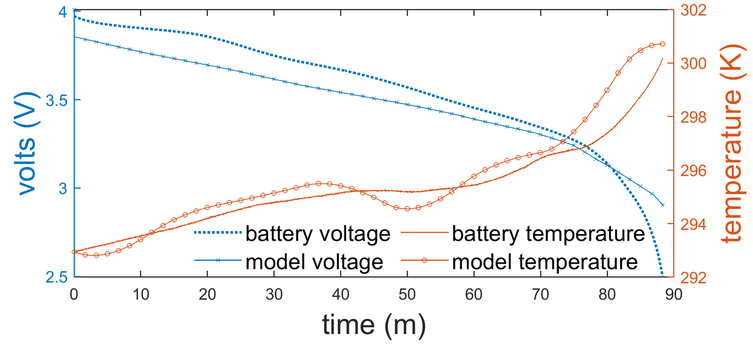
$$mc_{\text{cell}}\frac{dT}{dt} = I\left(U_{\text{avg}} - V\right) - IT_{\text{cell}}\frac{\partial U_{\text{avg}}}{\partial T} - Ah\left(T_{\text{cell}} - T_{\text{amb}}\right) - \dot{m}_{\text{liquid}}c_{\text{liquid}}\left(T_{\text{in,liquid}} - T_{\text{out,liquid}}\right)$$



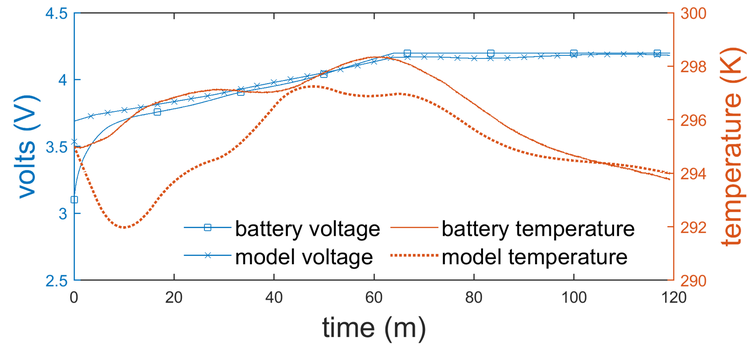

Conceptual diagram for the electro-thermal emulator hardware.

## Results

- Samsung 30Q battery was discharged and charged while recording its temperature, voltage, and current.
- The coupled electro-thermal model was initialized with the initial temperature and state of charge of the Samsung 30Q. The recorded current was then fed into the coupled model to test the voltage and temperature outputs.




Standard discharge of the Samsung 30Q cell.




Standard charge of the Samsung 30Q cell.

| Average Absolute Error | Voltage (V) | Temperature (K) |
|---|---|---|
| Standard Discharge | 2.93% | 0.10% |
| Standard Charge | 1.10% | 0.43% |

- The models have a good agreement with the physical battery.
- With treating a battery pack as a lumped system, the models can be scaled to represent full battery packs as any combination of the original cell.

[1] Anderson, Brad. “Electric Bus in China Erupts in Fire That Spreads to Four Others.” *Carscoops*, 8 June 2021, https://www.carscoops.com/2021/06/electric-bus-in-china-erupts-in-fire-that-spreads-to-four-others/.
[2] Ben. “Why Thermal Runaway Is the Real Killer in Battery Fires.” Zenaji, 31 Jan. 2022, https://zenaji.com/why-thermal-runaway-is-the-real-killer-in-battery-fires/.

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