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Enabling Safe Battery System Design through Electro-thermal Emulation

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Background

- Lithium-ion batteries, if used aggressively, can combust into an uncontrollable fire called thermal runaway.
- Commercial battery emulators only consider the electrical characteristics of a lithium-ion battery.

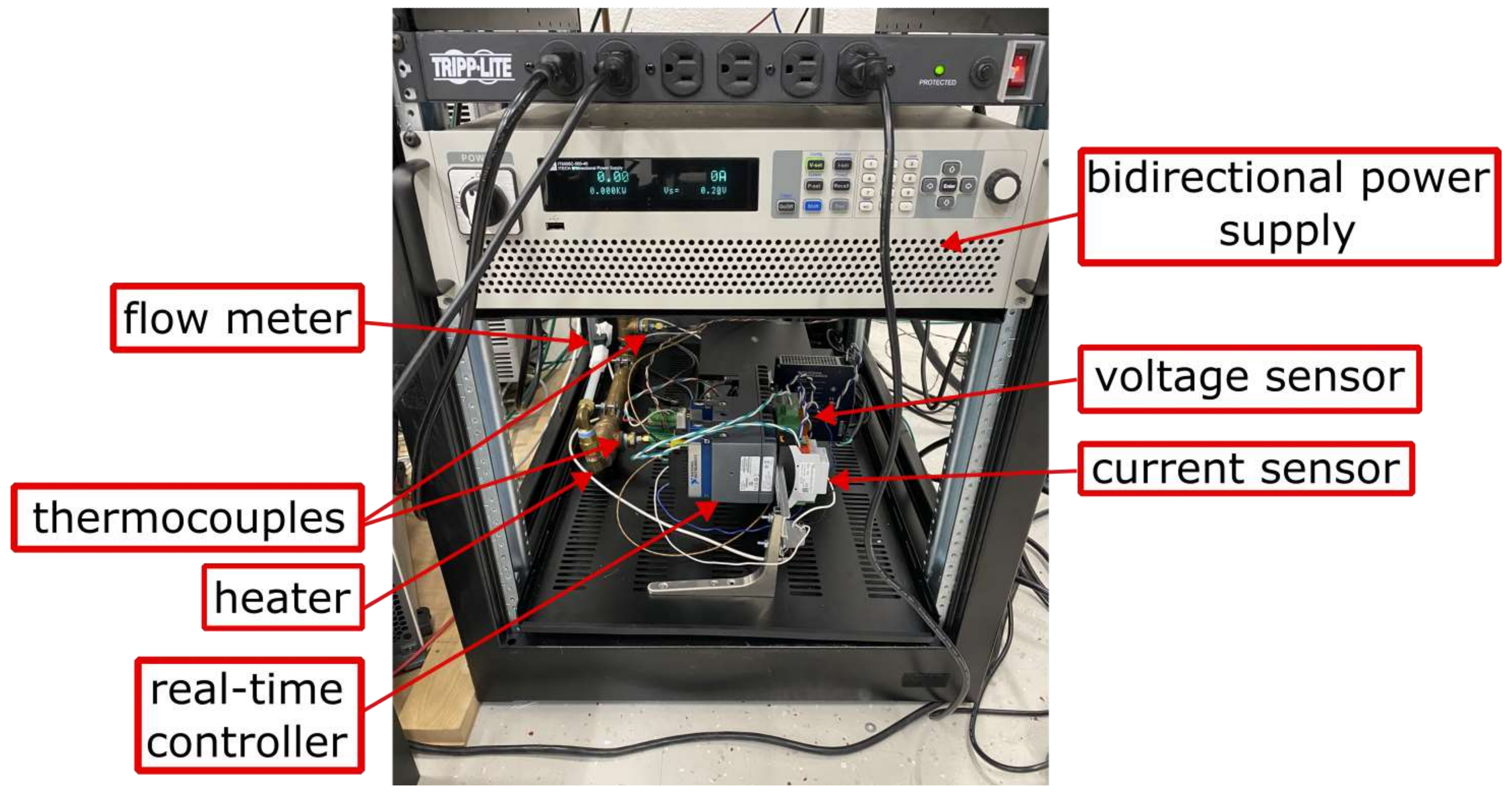
Luxury car's battery igniting burning five other cars in Sydney 2023 [1]

Tesla Megapack in Australia 2023 [2]

Key Points

- Battery emulator can emulate the coupled electrical and thermal characteristics of a lithium-ion battery.
- Thermal characteristics are physically emulated to allow for development of real cooling methods for powertrains.
- The electrical characteristics are also physically emulated to safely investigate how the battery will electrically affect a system when thermally and electrically stressed.
- With some assumptions, the experimental data can be taken from a single cell and then scaled to match any size battery pack to be emulated.

Design



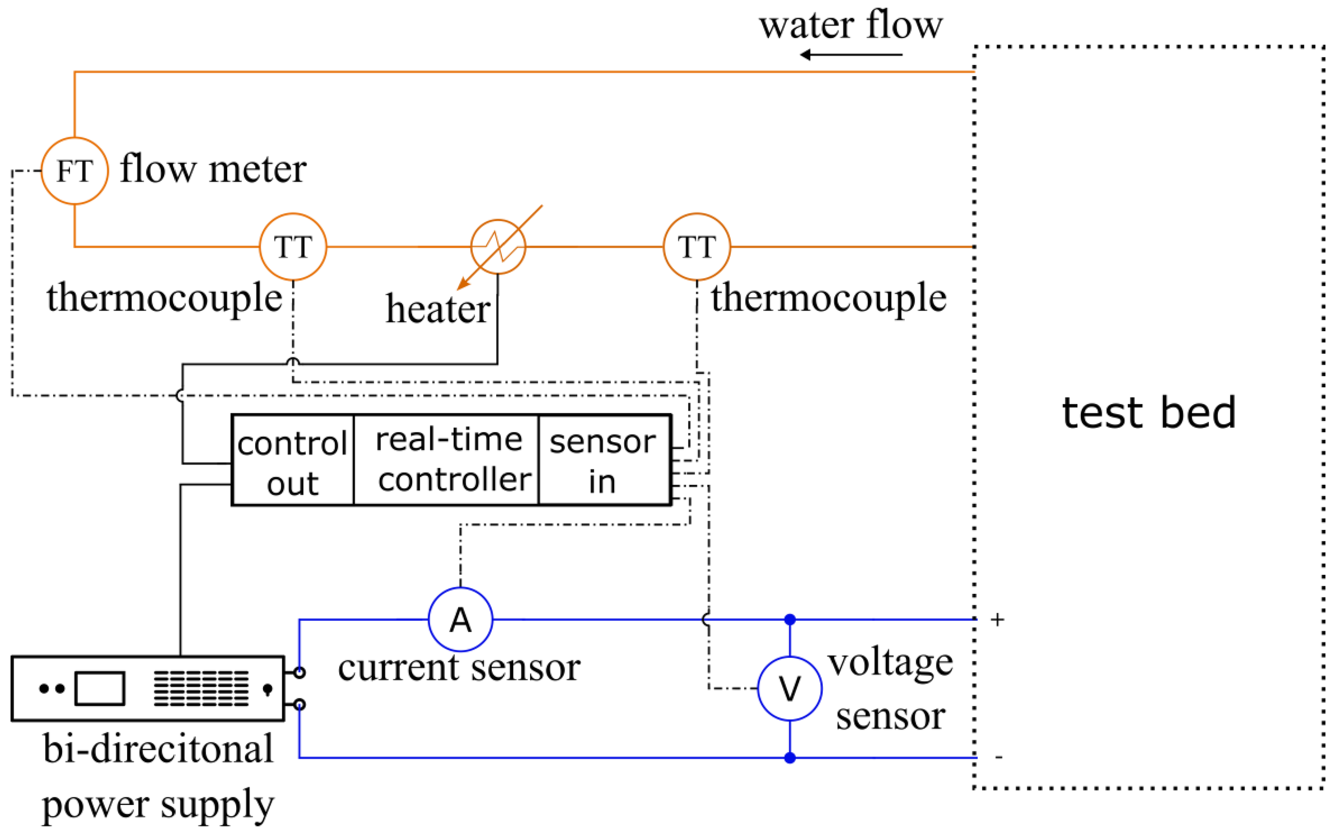
Physical hardware setup of the emulator

- 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 (2nd order ECM):

$$V_{\text{out}}(t) = OCV(SoC,T) - i(t_0)R_0(SoC,T) - V_{RC_1(SoC,T)} - V_{RC_2(SoC,T)}$$

- Heat generation model:

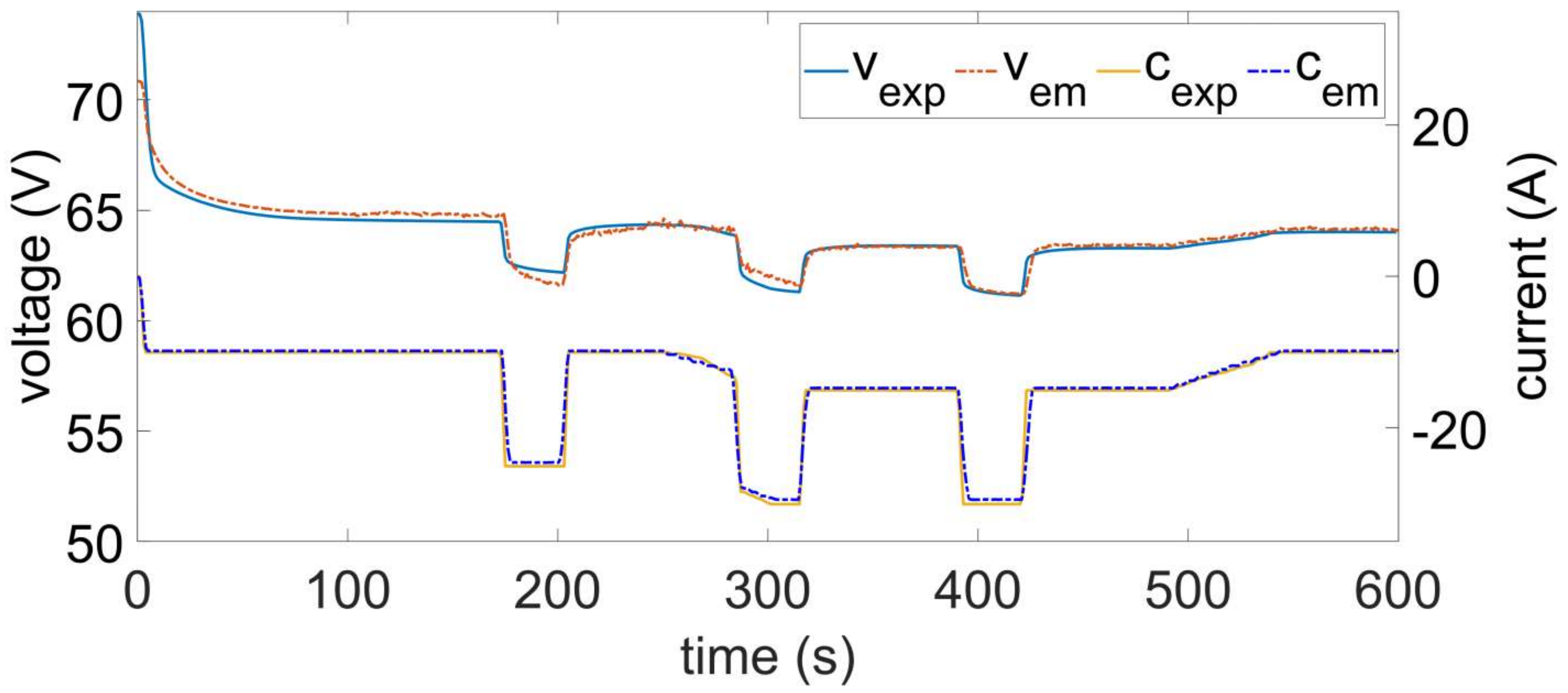
$$mc_{\text{cell}}\frac{dT}{dt} = I\left(U_{\text{avg}} - V\right) - IT_{\text{cell}}\frac{\partial U_{\text{avg}}}{\partial T} - Ah\left(T_{\text{cell}} - T_{\text{amb}}\right) - \dot{m}_{\text{liquid}}c_{\text{liquid}}\left(T_{\text{in,liquid}} - T_{\text{out,liquid}}\right)$$



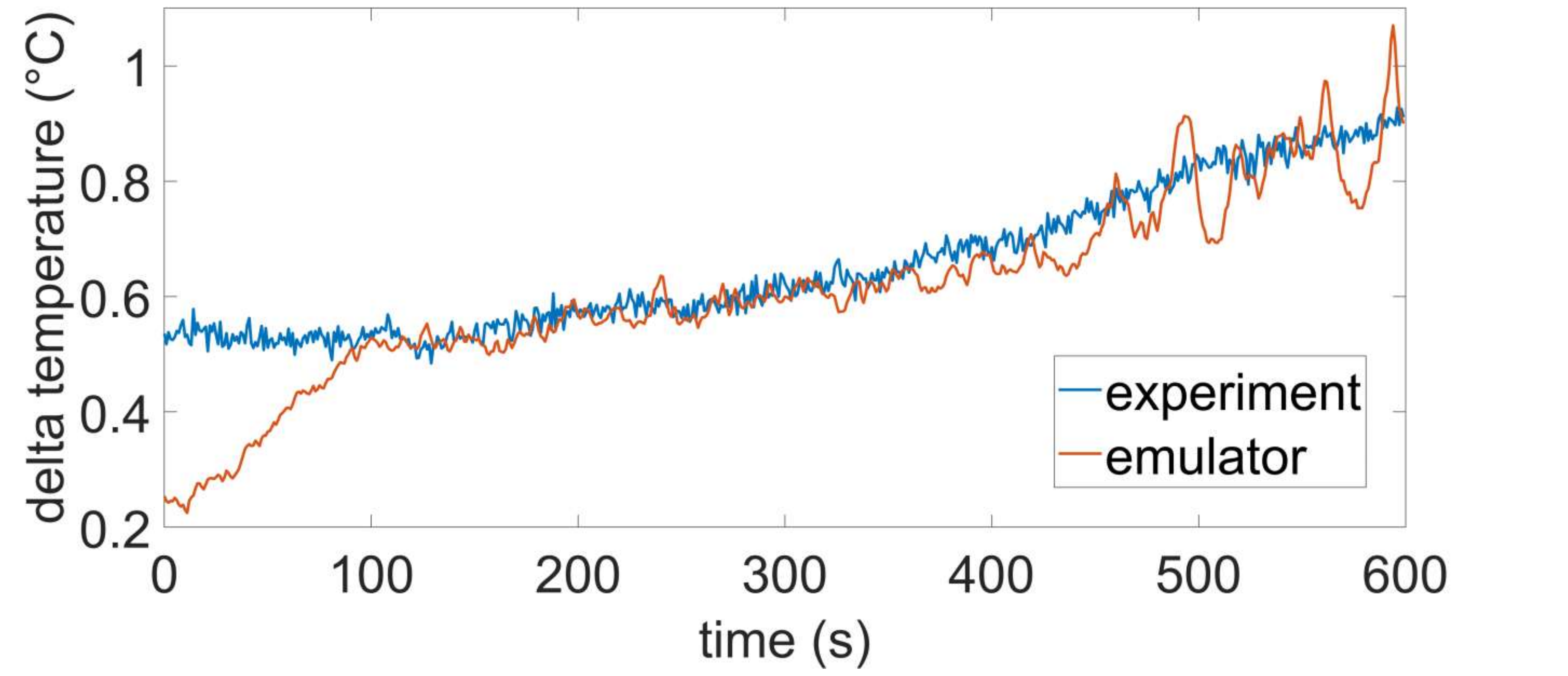
Conceptual diagram for the emulator hardware

Results

- Battery pack made up of K2 Energy 26650 cells (20s4p) was discharged with a load profile while recording its temperature, voltage and current.
- The emulator was initialized with the initial temperature and state of charge of the K2 battery pack. The recorded current and temperature was then fed into the emulator to test the voltage and temperature outputs.



Load profile test of K2 battery pack, experiment (exp) vs Emulator (em)



K2 pack experimental inlet-outlet temperature difference vs Emulator

Average Absolute Error	Voltage (V)	Delta Temperature (°C)
Emulator	0.37%	9.37%

- The emulator's outputs have a fair 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] Yiacoumi, Roulla. "Lithium-Ion Car Battery Explodes at Sydney Airport." *Information Age*, ia.acs.org.au/article/2023/lithium-ion-car-battery-explodes-at-sydney-airport.

[2] Peacock, Bella. "Australian Firefighters Contain Blaze at Tesla Battery Facility in Queensland." *Pv Magazine International*, 27 Sept. 2023, www.pv-magazine.com/2023/09/27/tesla-megapack-on-fire-at-big-battery-in-australia.

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