Oak Ridge National Laboratory

Impact of the Megapack Battery Cycle Life by Different Balancing Strategies

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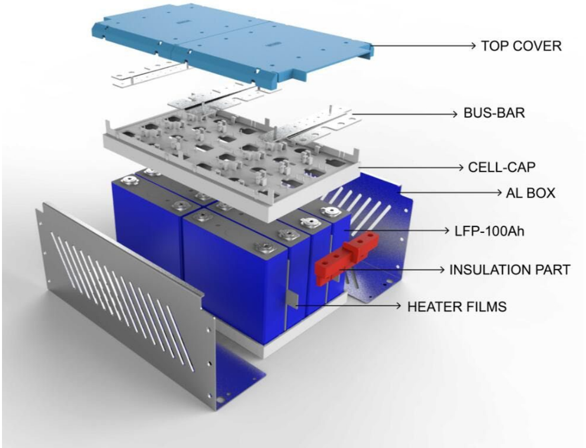
Outline

- Motivation
- Validation of the single cell model from cycling experiments
- Imbalances in modules/packs
- Active/Passive balancing strategies
- Modeling Results
- Software Release
- Next Steps/Conclusions

Motivation

Objective: Develop aging/degradation informed active battery management system (BMS) control to enhance lithium-ion battery integration into large scale grid storage.

https://power.tenergy.com/lg-21700-3-6v-5000mah-m50lt-li-ion-rechargeable-flat-top-battery/



https://www.ecolithiumbattery.com/battery-module/

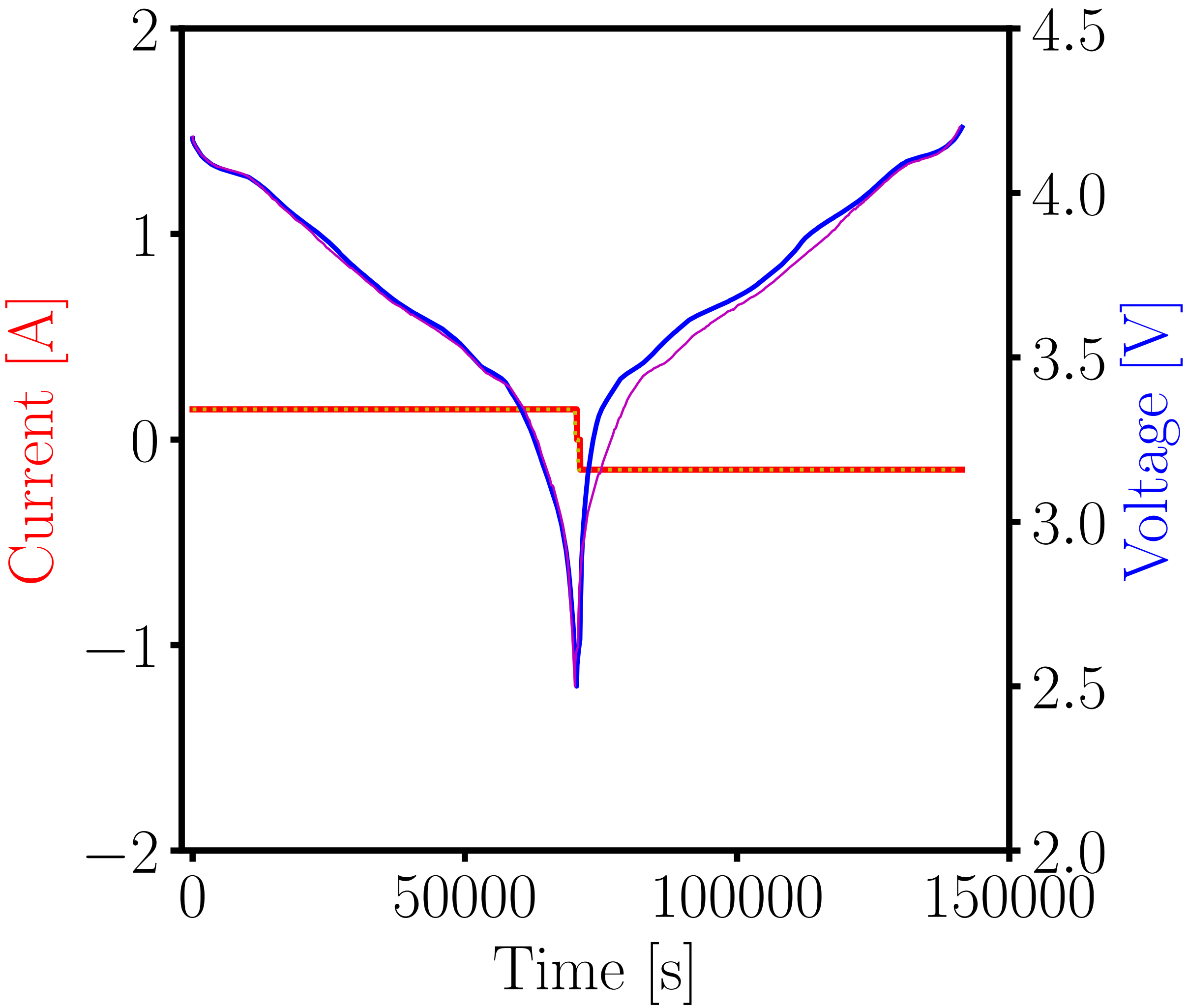
https://www.eba250.com/fast-growing-grid-scale-stationary-battery-storage/

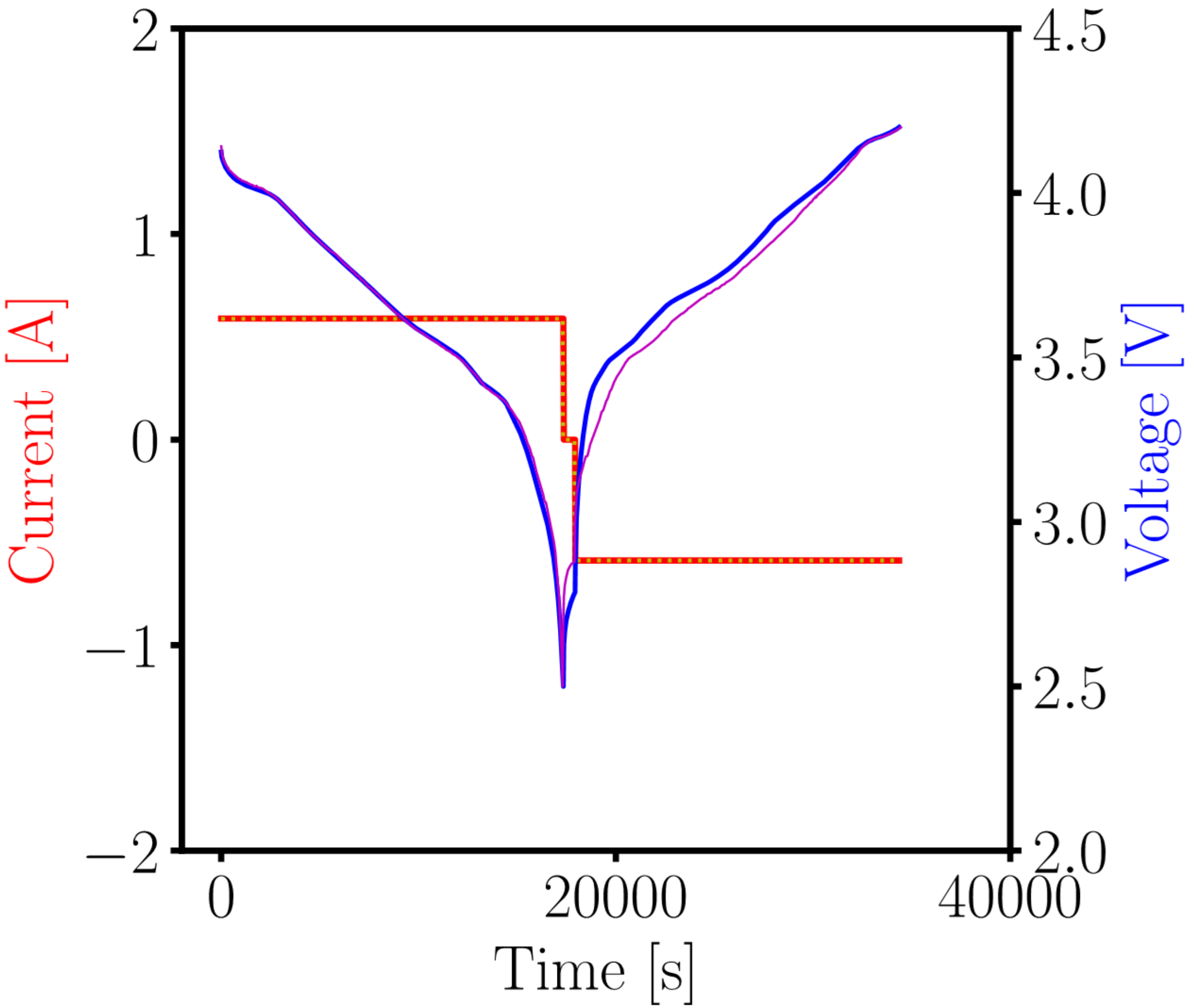
Cell level degradation:
- Cell chemistry, inhomogenities from manufacturing , cycling and storage conditions.
- Experimentally well studied.

Module level degradation:
- Cell level + module construction effects (busbars, cooling).
- Experimental analysis takes more time

Pack level degradation:
- Cell level + module/pack construction effects (busbars, cooling).
- Experimental analysis requires significant construction effort and time

Single cell validation results for 3Ah LG hg2 cell

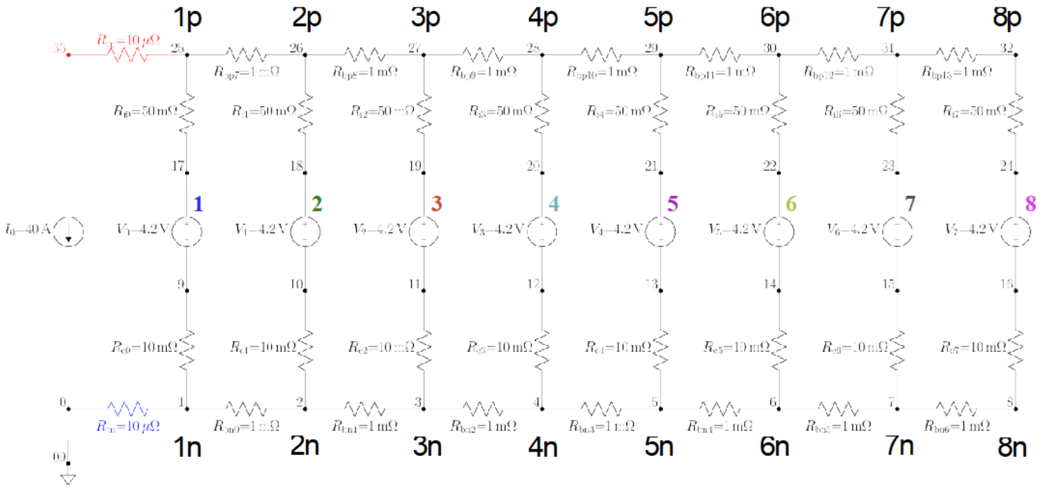


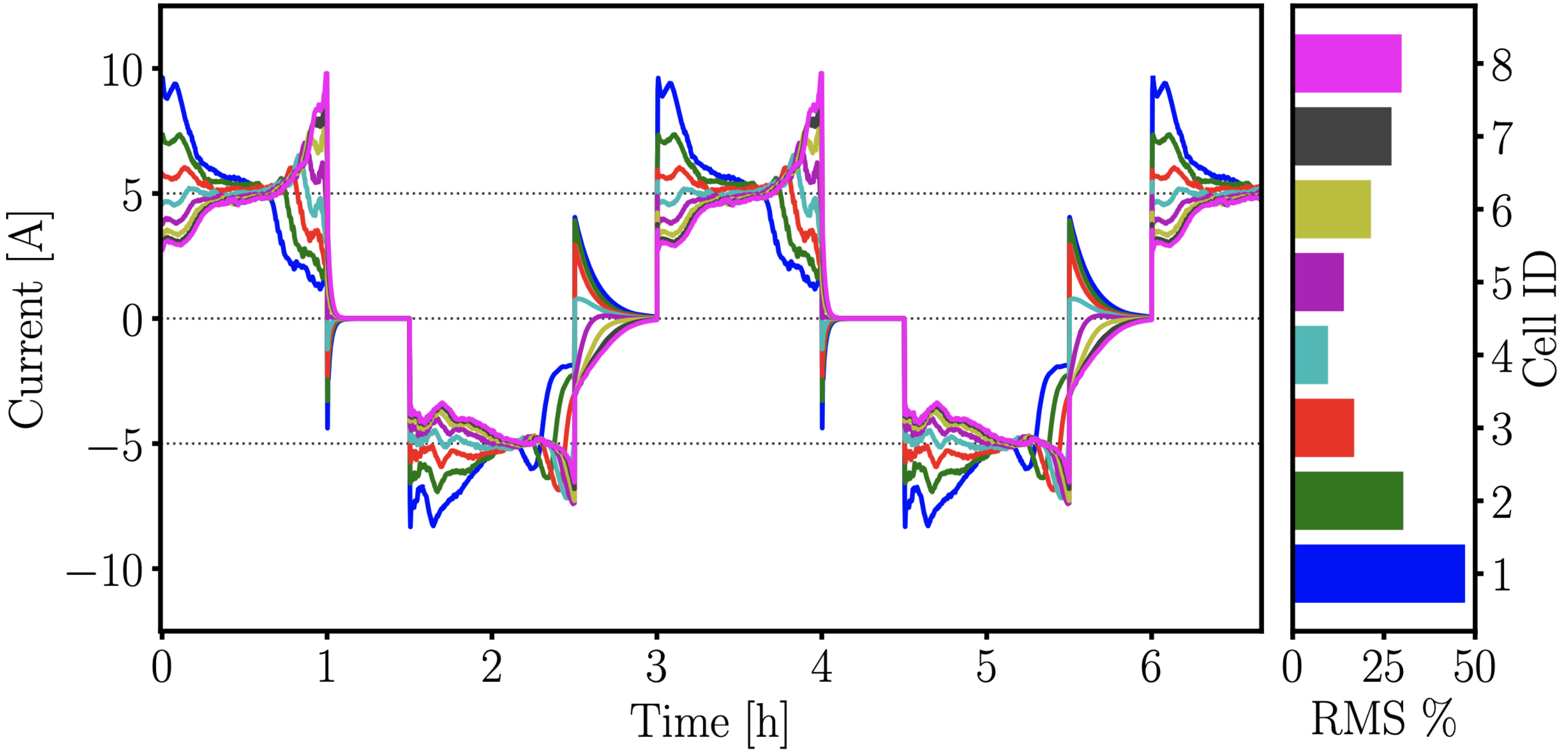


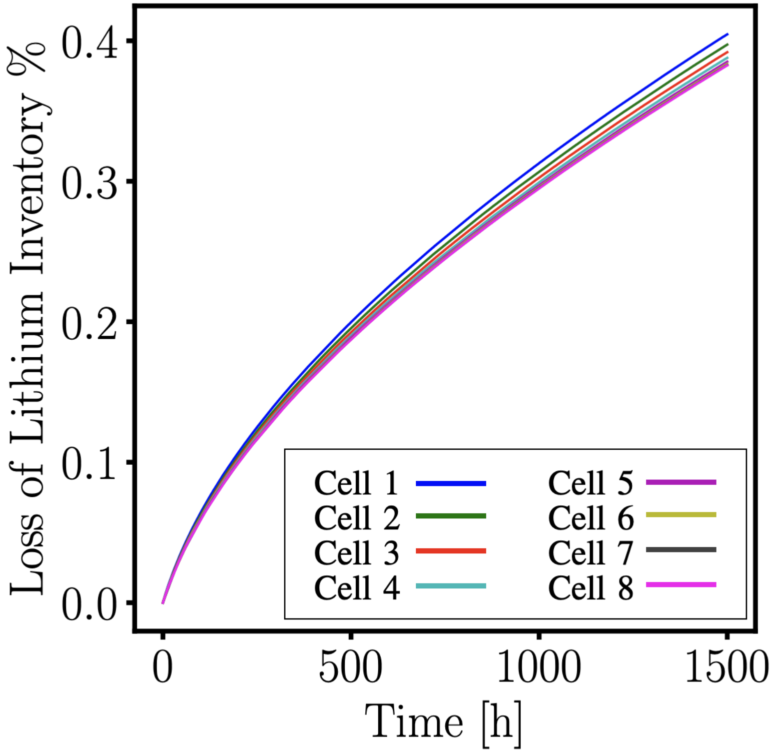
The experimental data for discharge at C/20 until 2.5V followed by 600 seconds rest and charge at C/20 until 4.2 V was used for optimizing the physics-based simulation parameters. Then the parameters were tested for a C/5 discharge-rest-charge cycle. Results show an RMSE of 1.4 % and an R^2 metric score of 0.98.

Current Imbalance in Modules

- Cells connected in parallel in a module experience imbalance in currents.
- Imbalance in currents causes heterogeneity in cell degradation during long term cycling of modules.
- Minimizing imbalance in the cell currents : the variation in SOC among cells is minimized, the aging variation is minimized across cells. Thus, a uniform degradation of cells implies an aging informed control of the modules and packs can be identified.

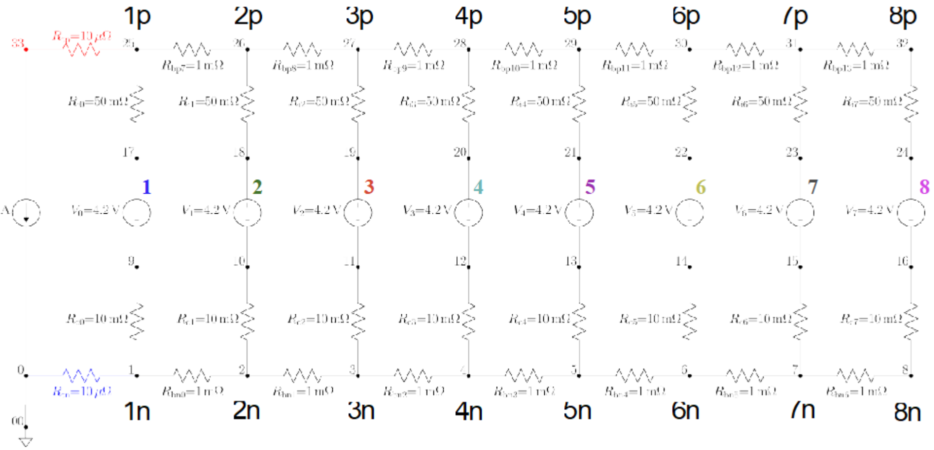


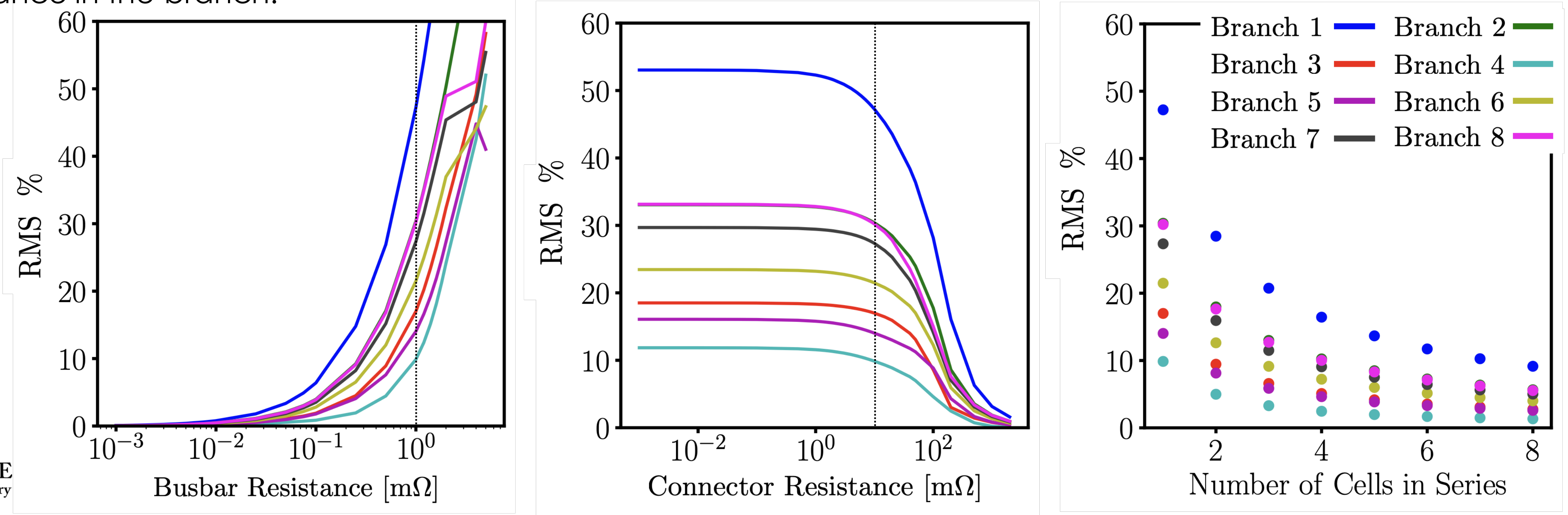




Passive current balancing methods

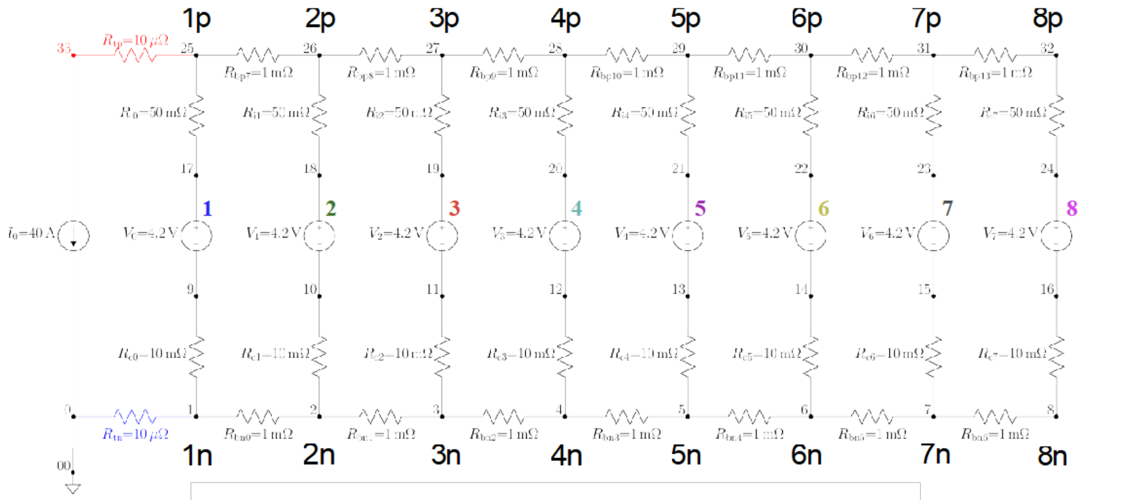
- The factors effecting current imbalance in modules and packs by construction were identified.
- Lower bus bar resistance reduces the current imbalance. May be impractical
- Increase in connector resistance minimizes current imbalance. Can potentially cause thermal issues due to loss of energy to heat.
- Adding cells in series to the parallel branches minimizes imbalance in the branch.

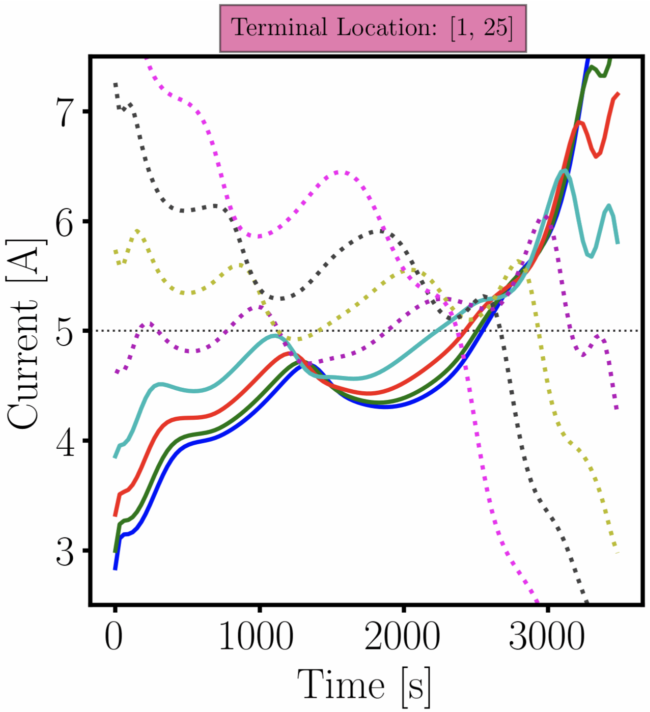


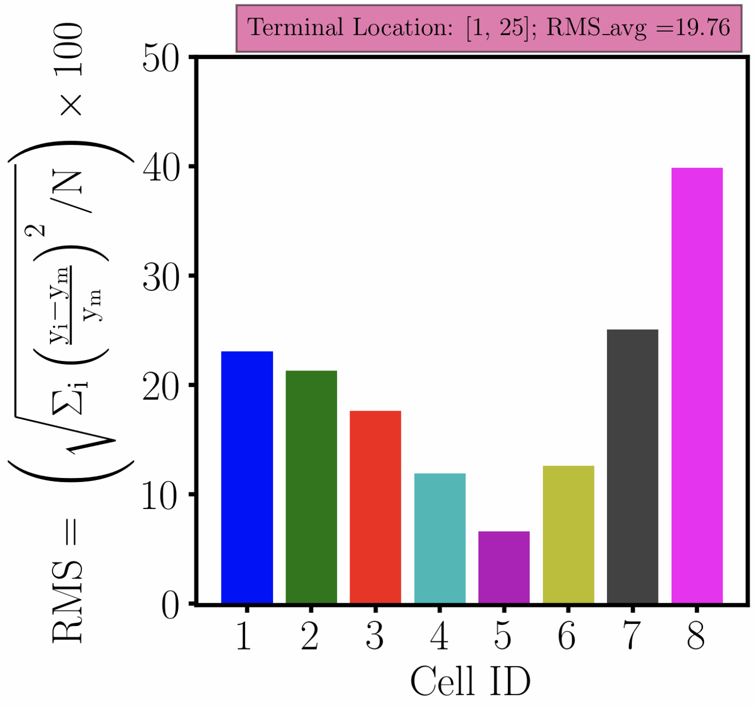


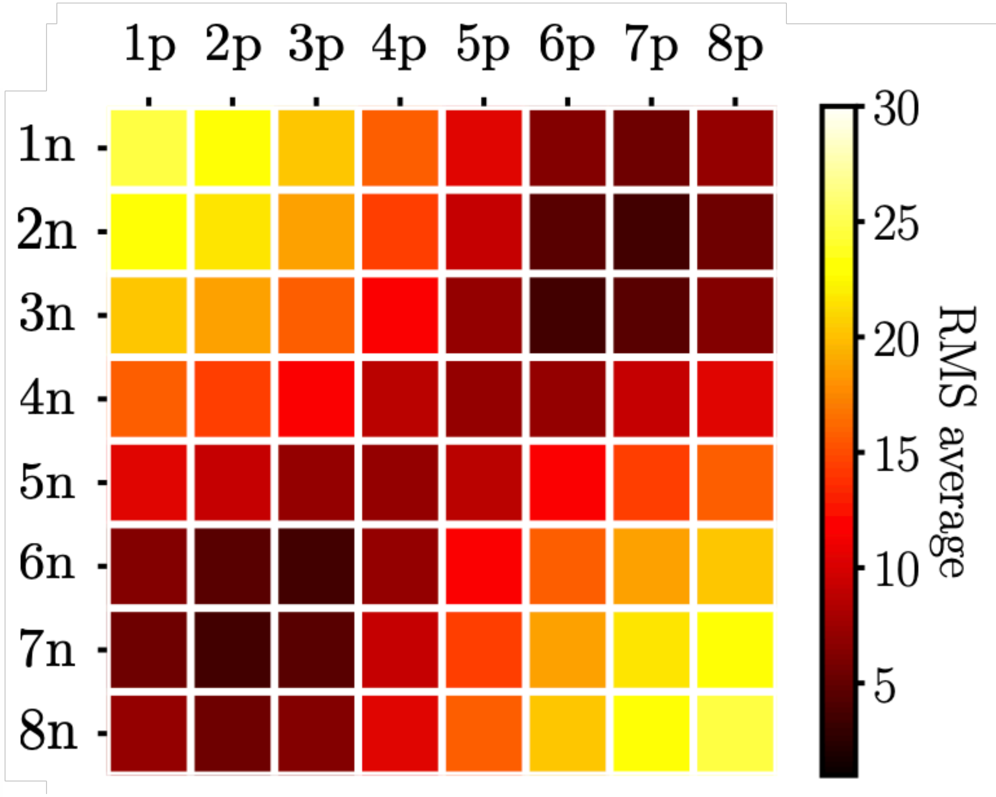
Terminal locations on current balancing

- Terminals at the end of the 8p1s module causes highest imbalance in currents.
- Effective terminal locations to minimize imbalance in 8P1S configuration are at nodes [2,31], [3,30], [6,27], [7,26]. Alternatively, [2n,7p],[3n,6p],[6n,3p], and [7n,2p].
- Terminal connections to intermediate parallel branches could minimize imbalance.

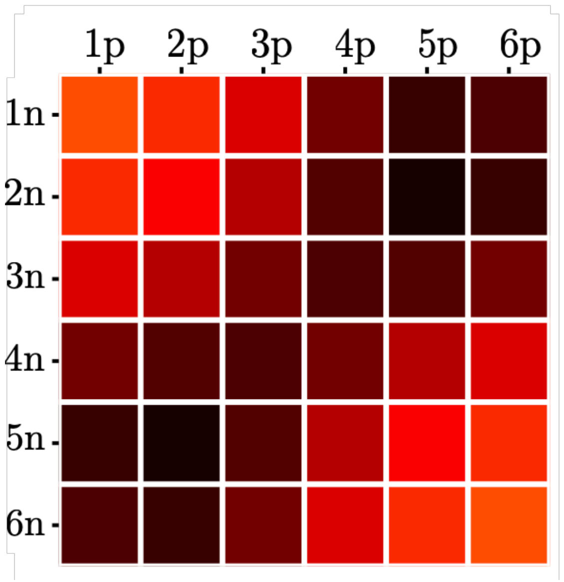


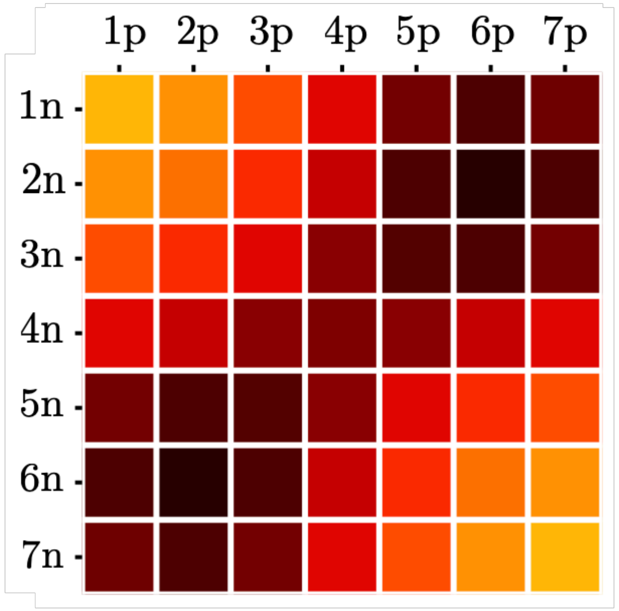


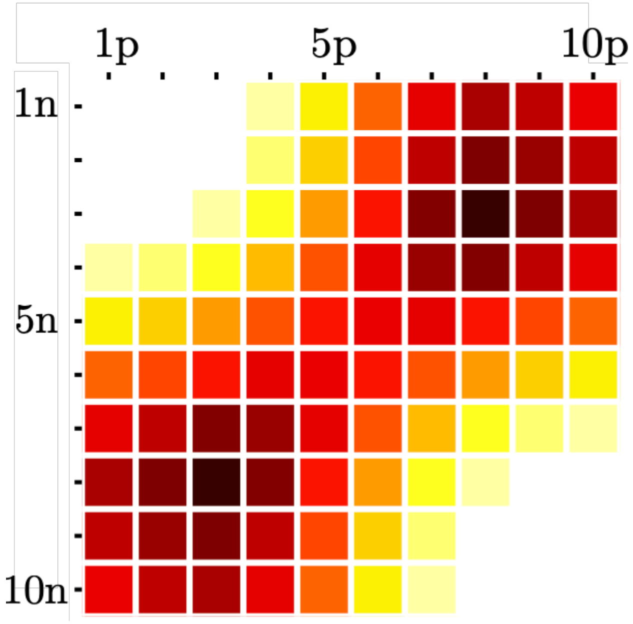




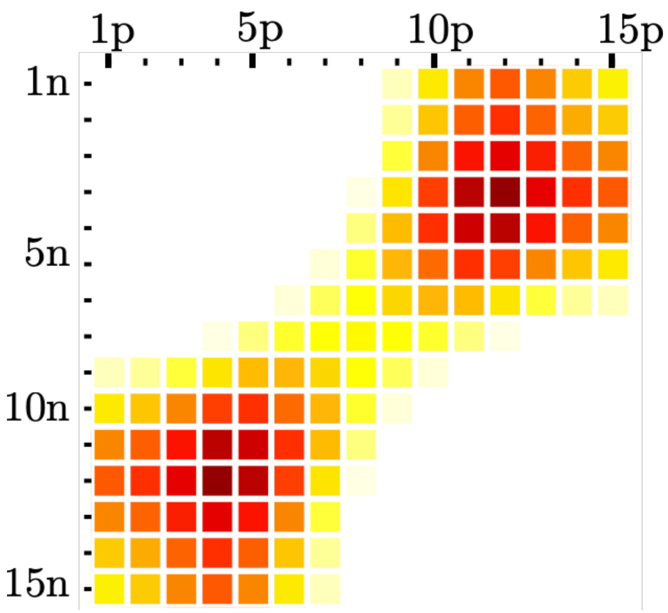
Terminal locations on current balancing

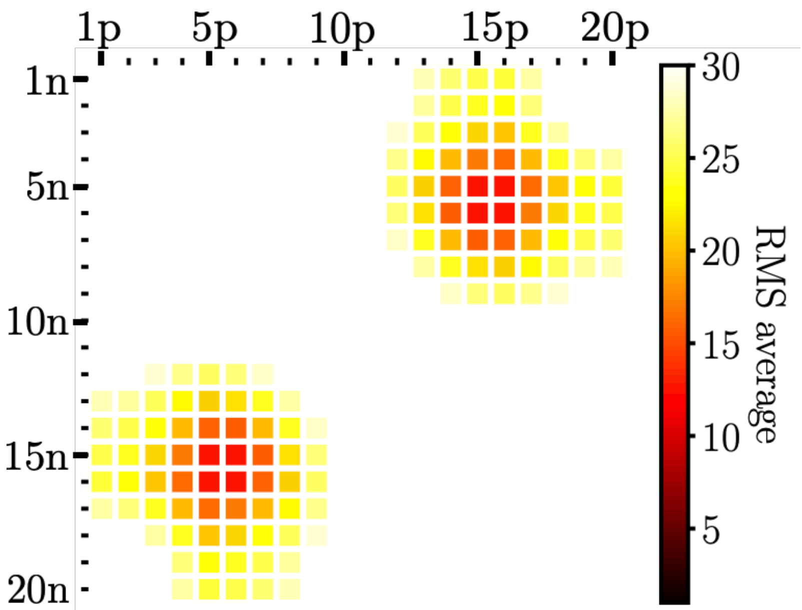




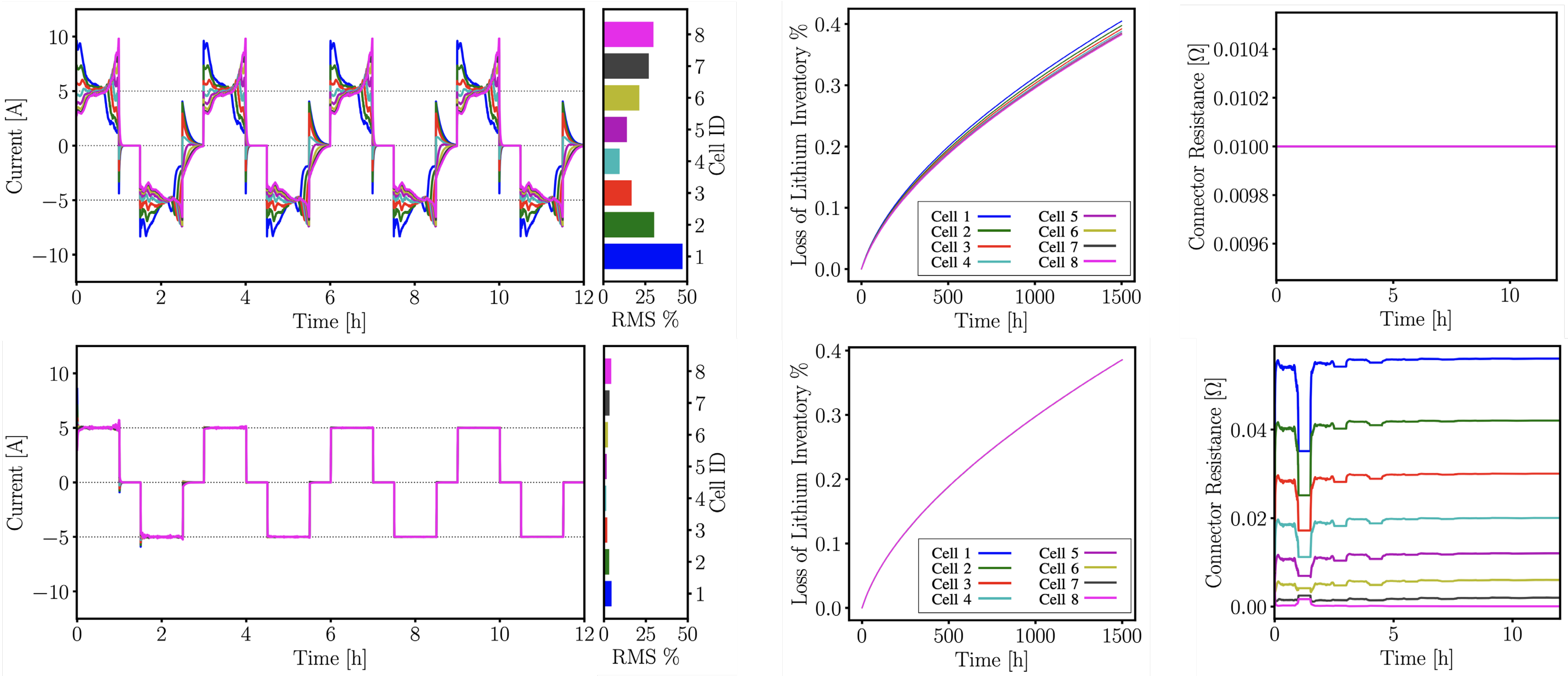


- For modules with n parallel connections n<=8, having terminals at 2nd and (n-1)th branch minimizes imbalance.
- As the number of parallel connection increase, terminals connected to intermediate branches have minimized imbalance.



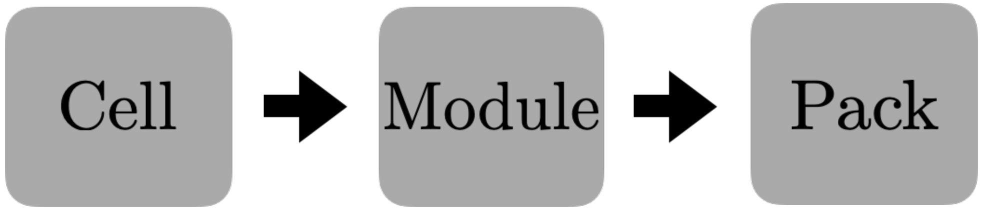


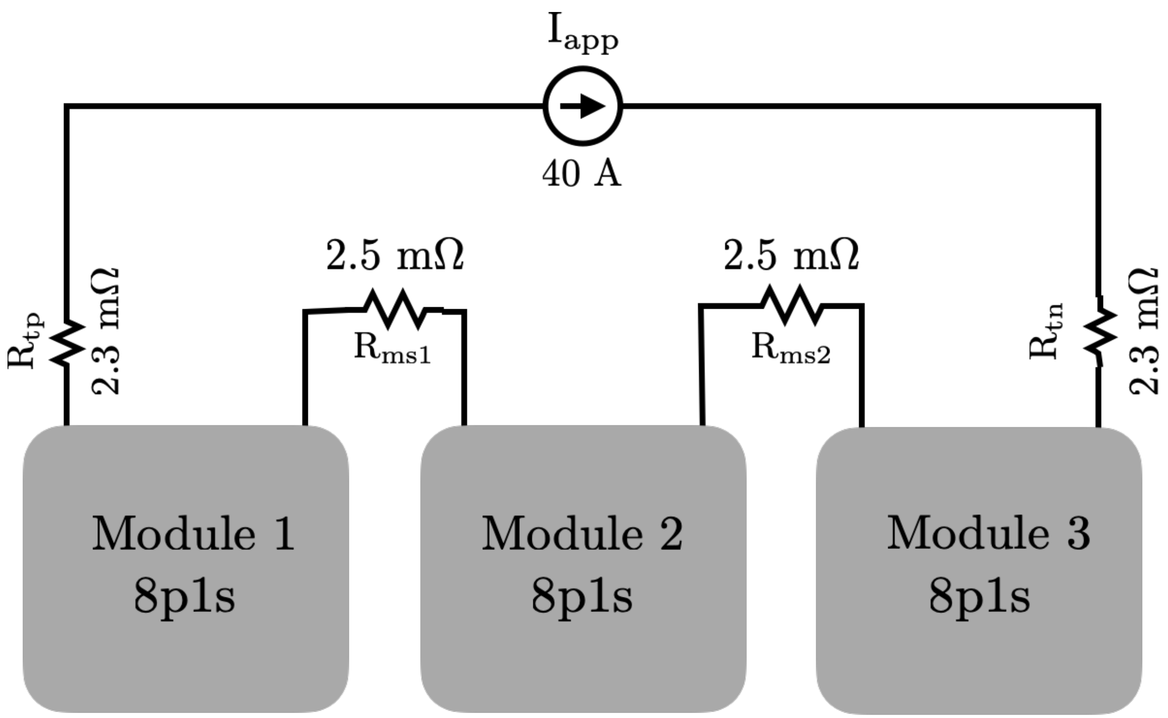
Active Current balancing



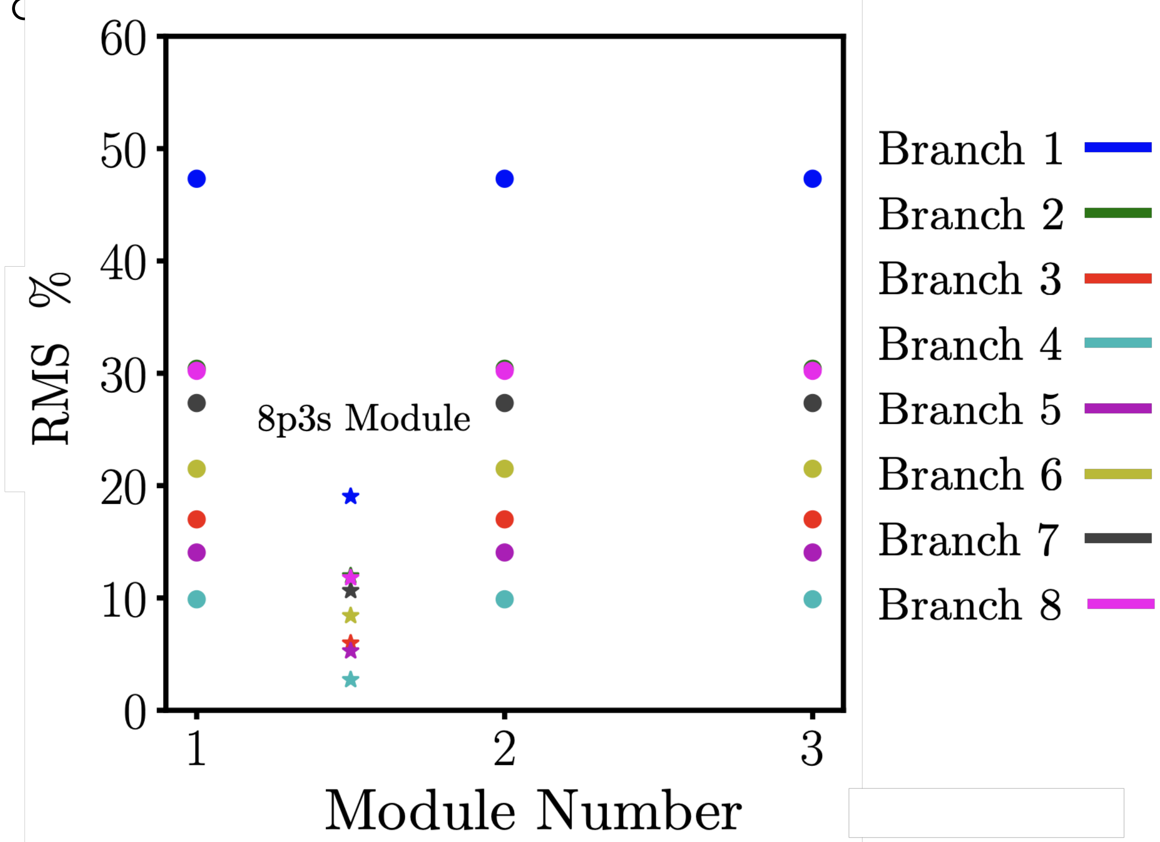
- Active balancing cell currents was achieved through a variable connector resistance that adjusts according to the magnitude of imbalance.
- The connector resistance adjusts to a constant values withing first three cycles.
- Active balancing minimizes the heterogeneity in degradation of the cells, therefore all the cells age uniformly in the module allowing easier identification of aging informed controls.

Cell-Module-Pack hierarchical construction

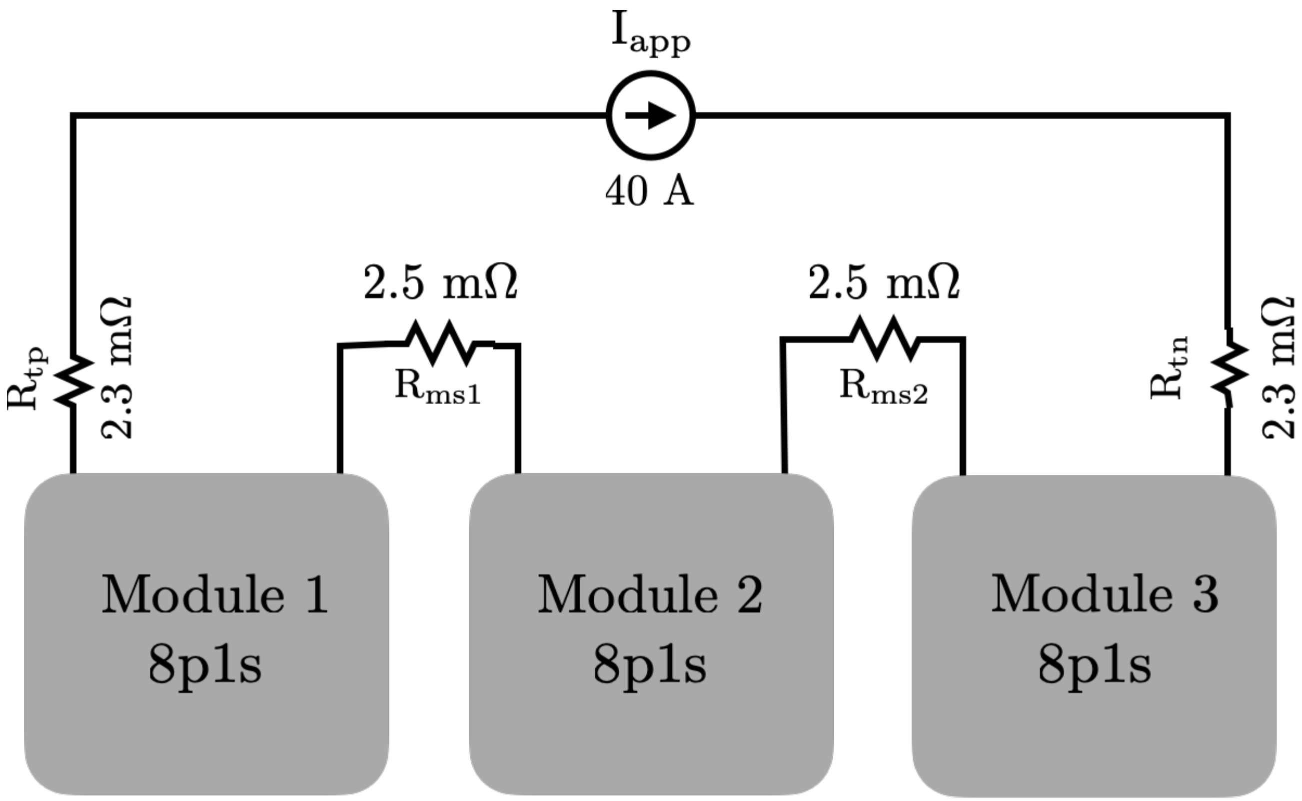


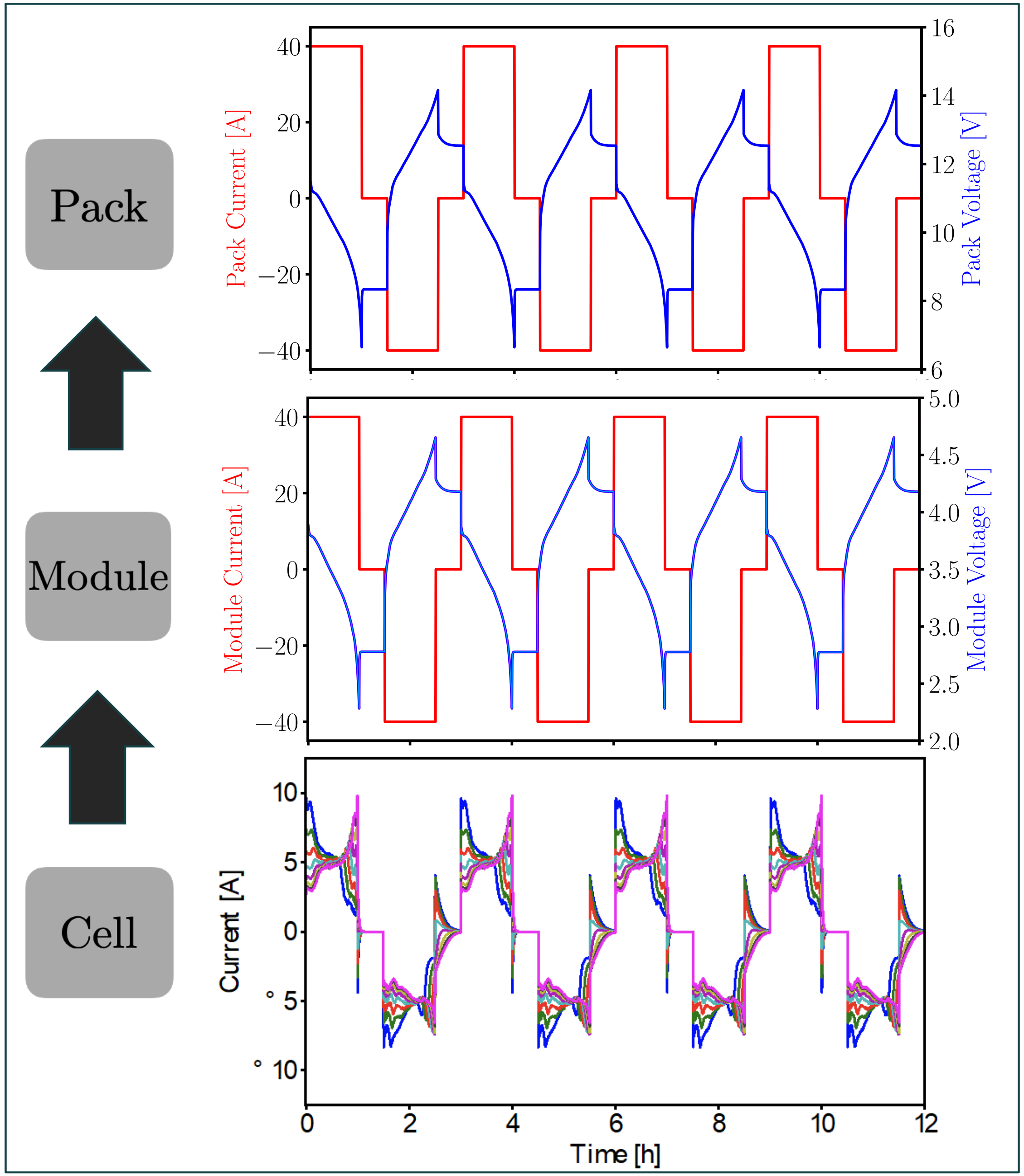


- Large scale battery packs follow a hierarchical construction from cells to modules to packs.
- A hierarchical circuit construction is essential to accurately predict the pack characteristics during cycling.
- A pack constructed from three 8p1s modules have different imbalance in currents compared to a pack represented as 8p3s circuit



Cell-Module-Pack hierarchy





- Modules connected in series experience same currents and the pack.
- All modules in series have same potential difference, since the effective impedance of the modules are same.
- Current imbalance across cells in the modules is same due to the module currents and voltages.

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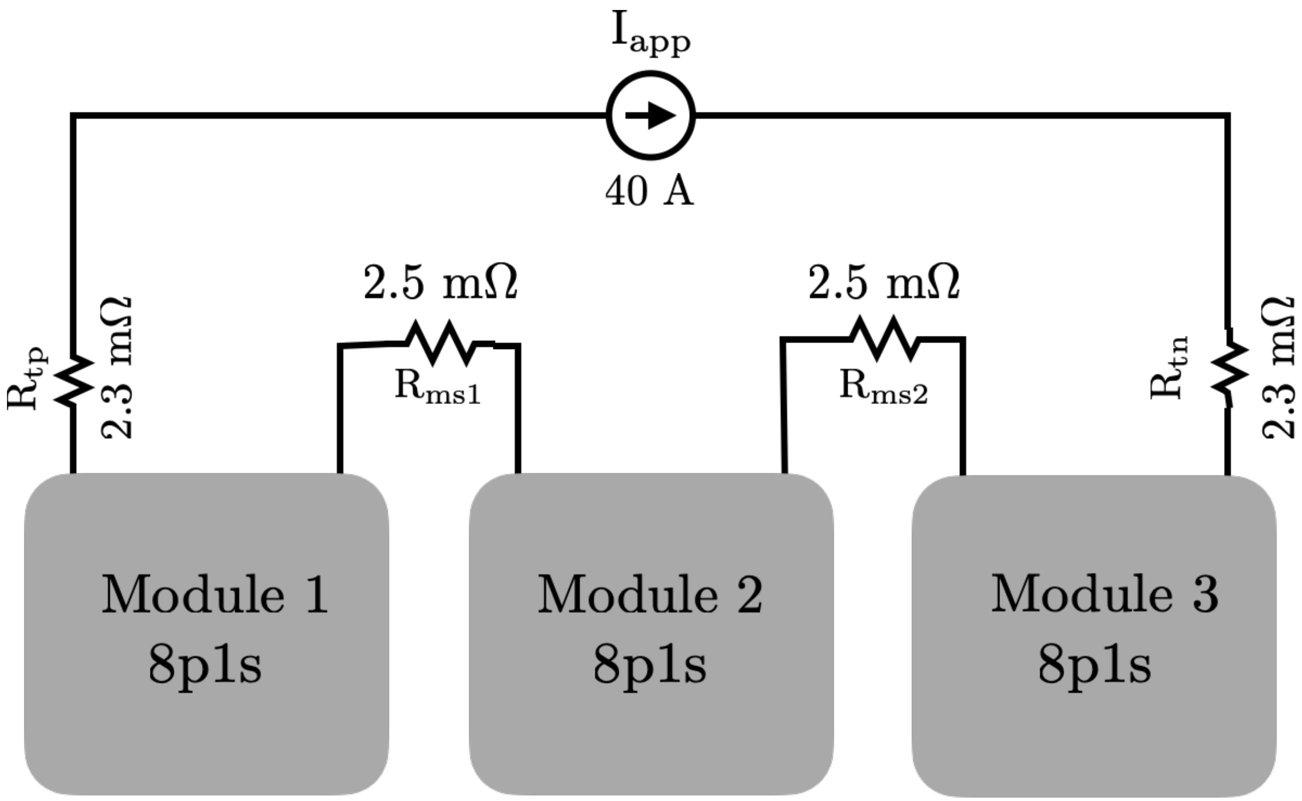
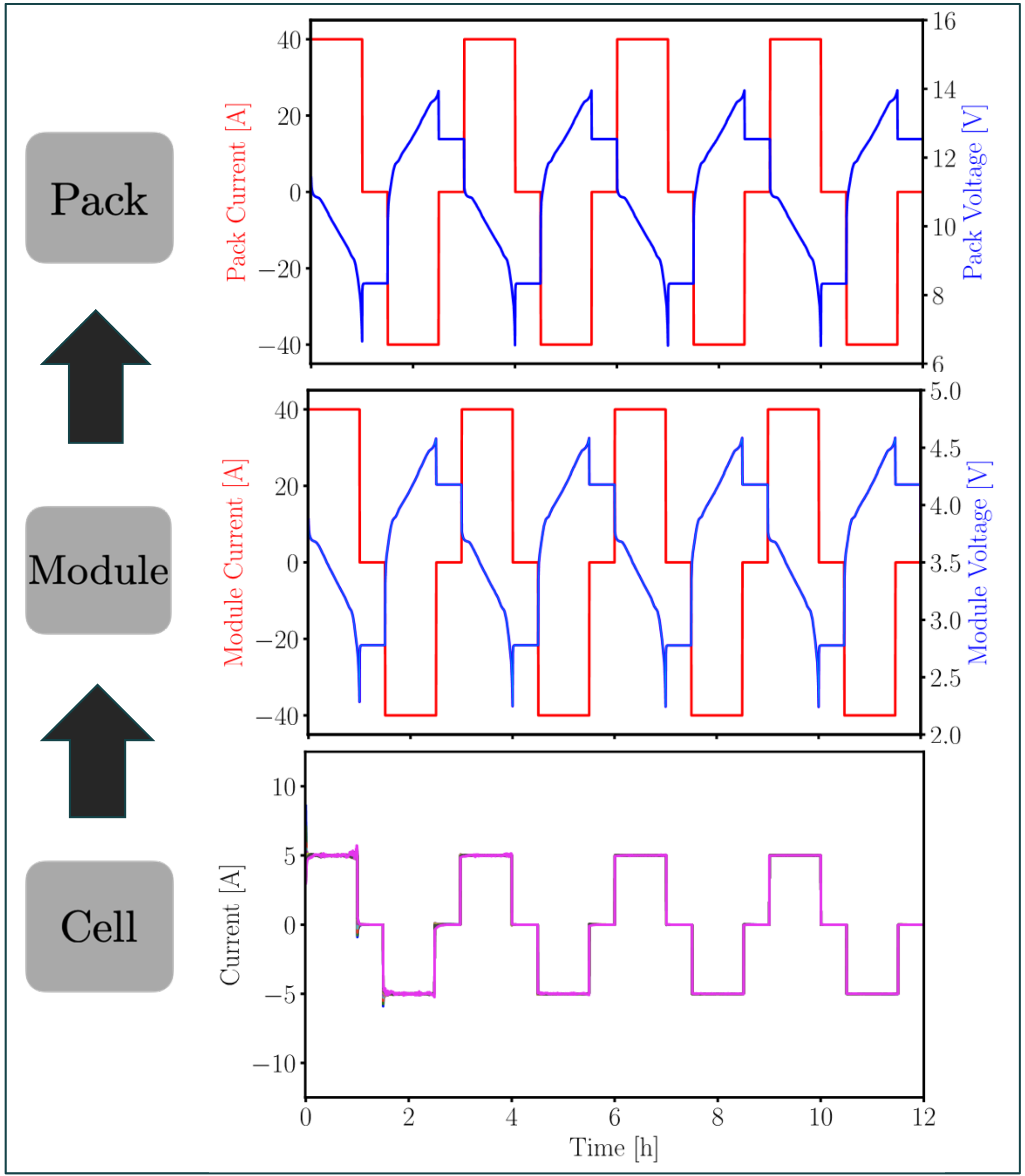
Cell-Module-Pack BMS





- Active cell balancing strategy through variable connector resistance was applied on each module.
- Since the modules experience same currents and voltages, a pack level control was not required for this case.
- Current imbalance was minimized across cells in the modules.

Summary and Overview of tools developed for pack scale analysis

- The physics-based framework developed here is useful to identify optimal pack construction strategies, starting with information about individual cells and circuit elements (Resistances, capacitance, Inductances).

- The study shows a uniform aging of cells in a pack is achievable through an appropriate choice of resistive elements, terminal locations and active balancing from variable resistance.

- Appropriate hierarchical construction of pack level circuits from modules and cells allows for a physically accurate representation of aging in the pack, module and cells.

- Although the module constructed and tested is a proof of concept, the physics-based framework is readily applicable to real module and pack constructions.
  - The individual cell data for 5Ah LGM50 cells from pybamm (Okane 2022 data set) was used, while the resistances were chosen from the simulation work of Vikrant *et al*.

- Liionpack , an opensource code is utilized for the following analysis.
  - Liionpack was modified to accept non-uniform busbars and connector resistances to simulate a module or a pack.
  - Solver improved to accept capacitor and inductor circuit elements in the module and pack circuits to create a physically accurate BMS circuits.
  - Solver has a variable connector resistance switch to actively balance the currents in the circuit.
  - Pack and module circuit hierarchy has been implemented within liionpack to create a pack level circuit with module information.

Next Steps

- Demonstrate hierarchy of BMS/EMS systems to improve cycle life with MWh systems
- Develop ageing aware BMS to demonstrate cycling improvement at scale.
- The pack level simulations backed with experimental data for module and cell, will be tested with realistic load cycles at different configurations to analyze degradation.
- Improve computational efficiency of liionpack. Utilize available computational resources simulate a full life cycle of a pack within a day.

Publications

- Tranter, T., Timms, R., Sulzer, V., Planella, F., Wiggins, G., Karra, S., Agarwal, P., Chopra, S., Allu, S., Shearing, P. and Brett, D., 2022. liionpack: A Python package for simulating packs of batteries with PyBaMM. *Journal of Open Source Software*, *7*(70)

- Vikrant, K.S.N., Tranter, T.G., Wiggins, G.M., Brett, D.J. and Allu, S., 2024, January. Ageing Studies of Mega Battery Packs for Grid Storage Applications Using Physics Based Modeling. In *2024 IEEE Electrical Energy Storage Application and Technologies Conference (EESAT)* (pp. 1-6). IEEE.

- A. Surya Mitra, Yuliya Preger, Srikanth Allu, A computational study to extend the megapack battery cycle life by different balancing strategies (under preparation) 2024.

Acknowledgements:

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