WHY DO CELLS IN A BATTERY PACK GO OUT OF BALANCE?

Investigating the role of pack inhomogeneities in beginning of life imbalance: A simulation study

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ABSTRACT

While the tendency of battery packs towards imbalance is widely acknowledged, underlying contributing factors are poorly researched in academic literature.

This study investigates the effect of inhomogeneities on beginning of life imbalance. Packs with parameters of interest are modelled and current distributions across 4S4P packs are visualised.

It is found that transient imbalance in packs, measured while under load, increases with the addition of parallel strings and with wider busbar resistance distributions. This likely drives inhomogeneous degradation of pack cells. Further, open circuit faults in busbars appear to cause permanent imbalance and severe underutilization of pack capacity.

MOTIVATION

Figure 1: Pulse discharge section of characterisation showing cell strings unbalanced. [1]

- Previous work [1,3] has shown that cells in a 3s pack appear to go out of balance and arrange in ascending voltage order with minimal cycling.
- It is thus worth investigating if pack inhomogeneities are contributing factors to beginning of life imbalance, or if imbalance is exclusively degradation dependent.

METHOD

- An Equivalent Circuit Model (ECM) of Molicel P42A cells with no degradation input are used to construct pack configurations of interest in Simscape.
- Busbars are modelled as interconnectivity resistances with nominal value 1mΩ. Scopes to measure pack and cell level currents and voltages are present.
- Cycler adapted from WMG Simscape Battery Library[2] performing the protocol: CCCV charge -> Rest -> CC discharge -> Rest

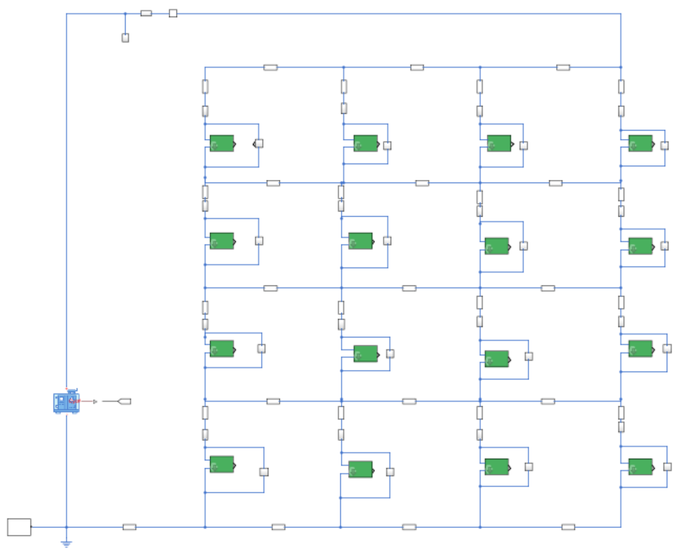

Figure 2: Representative 4s4p pack connected to cycler modelled in Simscape

Scan the QR code to visualize the flow of current in the pack grid under various simulated conditions alongside corresponding dynamic individual cell current and voltage profiles

NUMBER OF PARALLEL STRINGS

- Current fluctuation in pack increases as strings are added due to increased potential for circulation.
- Current profiles are observed to be symmetrical across diagonal terminal connections.
- Non-uniform cycling could lead to degradation driven imbalance.

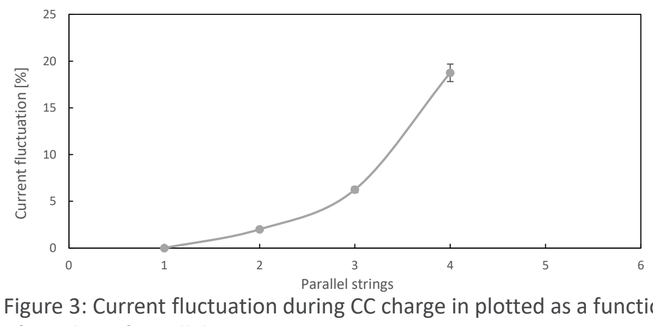

Figure 3: Current fluctuation during CC charge in plotted as a function of number of parallel strings

BUSBAR MANUFACTURING VARIATION

- Busbar manufacturing variation modelled as Gaussian distribution of resistances R~N(1,0.01)
- Terminal voltages converge during rest periods - transient imbalance only

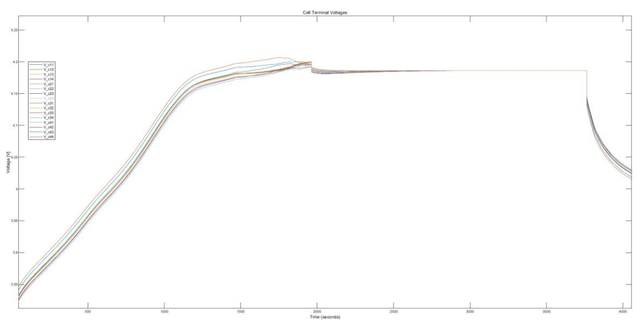

Figure 4: CCCV charge and charge rest – individual cell voltage profiles for an inhomogeneous pack with normally distributed resistances

BUSBAR OPEN CIRCUIT FAULTS

- Effect of parallel busbar fault heavily location dependent
- Currents can loop around an interior fault to a greater extent than a fault at the periphery of the grid
- Series open circuit faults cause permanent, causing three distinct profile groupings as in peripheral parallel faults.

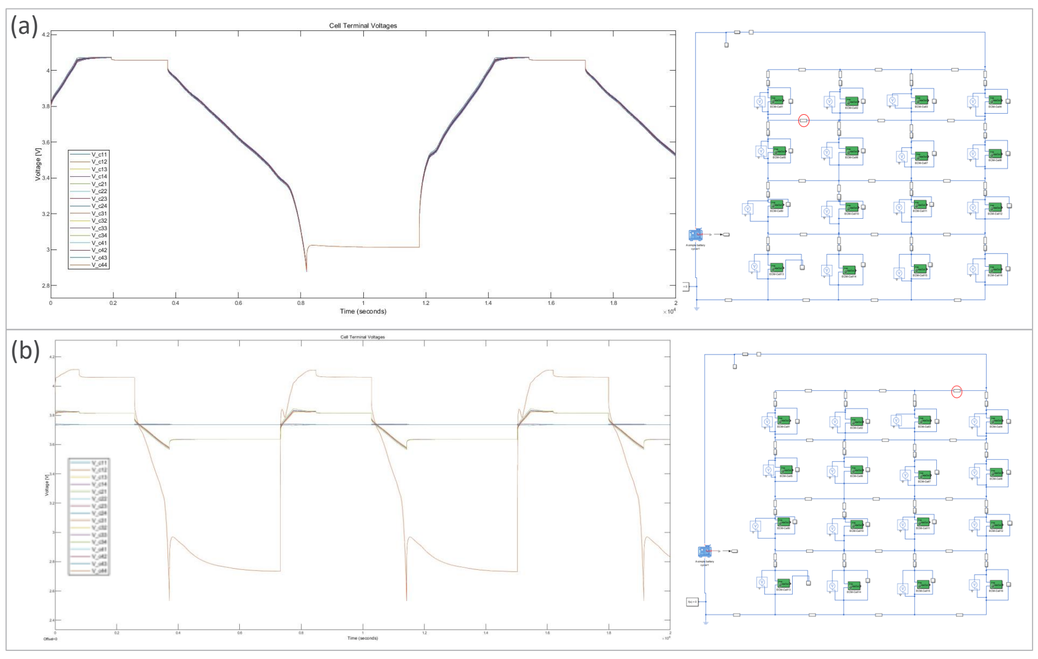

Figure 5: (a)Internal parallel busbar fault (b)Peripheral parallel busbar fault

NB: Faulty busbar set to 1GΩ to simulate open circuit condition

CONCLUSIONS/IMPLICATIONS

- Both transient and permanent imbalance are possible due to pack inhomogeneities at beginning of life.

Simulated Condition	Effect on cell imbalance
Varying number of parallel strings	Transient imbalance while cycling
Gaussian distribution of busbar resistances	Transient imbalance while cycling
Open circuit fault across parallel strings(peripheral)	Permanent imbalance
Open circuit fault across parallel strings(internal)	Transient and negligible imbalance
Open circuit fault between cells in series	Permanent imbalance

- Transient imbalance can result in uneven degradation, which is a potential cause of permanent imbalance making it a good candidate for further investigation.
- This study can inform manufacturing processes, define tolerances for pack components and select a suitable balancing mechanism

FUTURE WORK

- Expand simulation to include thermal gradients and boundary conditions.
- Experimental validation of simulation through development of test pack (fig. 6) capable of monitoring individual cell voltage and current in real time. Does changing busbar and wire bond thicknesses affect the magnitude of imbalance experimentally observed?

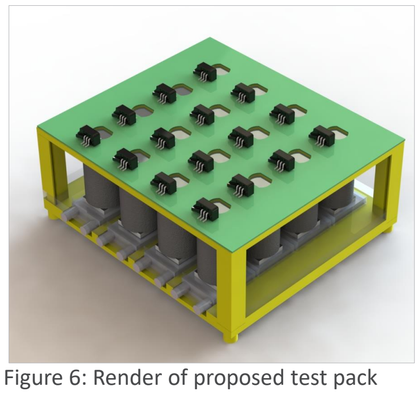

Figure 6: Render of proposed test pack

REFERENCES

1. Malik,M., Scaling Battery Degradation to a Pack Level, 2022
2. Widanage, D (2023) Simscape-Battery-Library(Version 2.0.0) [Source code]. https://github.com/WDWidanage/Simscape-Battery-Library
3. Ren, Y., Liu, K., Thomas, Widanalage Dhammika Widanage and Marco, J. (2022). Current Distribution and Anode Potential Modelling in Battery Modules with a Real-World Busbar System. *IEEE Transactions on Transportation Electrification*, pp.1–1.

INTERN BIO

Atulit is studying mechanical engineering at Imperial College London and completed his FUSE internship with IONETIC and the Electrochemical Science and Engineering Group. He aims to forge a career at the intersection of academia and entrepreneurship, perhaps as a research scientist at a start-up.

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