Analysing Battery Pack Balancing Strategies

Analysing the effects of pack balancing and the distribution of cell string voltages during characterisation and degradation cycling

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ABSTRACT

Battery packs for automotive applications are built from hundreds and thousands of individual battery cells, connected thermally and electrically. In this project, the necessity of pack balancing is studied by analysing the distribution of cell string voltages in a pack that undergoes accelerated degradation through rapid cycling. The pack was balanced every 50 cycles to study the effect of balancing on the pack. It was found that balancing is crucial to ensure the maximum voltage windows of the pack are utilised. Further analysis questioned if the type of cycler used affected the data obtained. Data from these packs showed that terminal cells always hit the voltage limits and that the cells string voltages followed a probable pattern based on their location on the pack during cycling. This led to the second ongoing experiment where packs of different configurations are run on a different cycler.

METHOD

The experiment in split into 3 main sections: **characterisation, degradation cycling** and **active balancing**. Characterisation consists of 2 components: Discharging & Charging and Pulse Discharges at 3 cut off voltages. Characterisation is conducted to evaluate the capacity of the pack at the end of each degradation cycle. Degradation cycling is conducted by rapidly charging and discharging the pack for 50 cycles. The degradation testing conducted is an accelerated simulation of actual pack degradation.

BACKGROUND & MOTIVATION

Balancing strategies, a critical part in the operation of battery packs is the strategy used to control the flow of current between cells. For maximum longevity, the balancing strategy should positively affect the performance of the pack throughout its lifetime. Active balancing, as shown in Figure 1, comprises of the cells being charged by various degrees to ensure that the final voltages of the cells are the same. Despite this topic being researched by both industry and academia, important questions remain over what the best balancing is, with some suggesting even that balancing may not be necessary. The aim of the experiment is to investigate the necessity of balancing to idealise pack output.

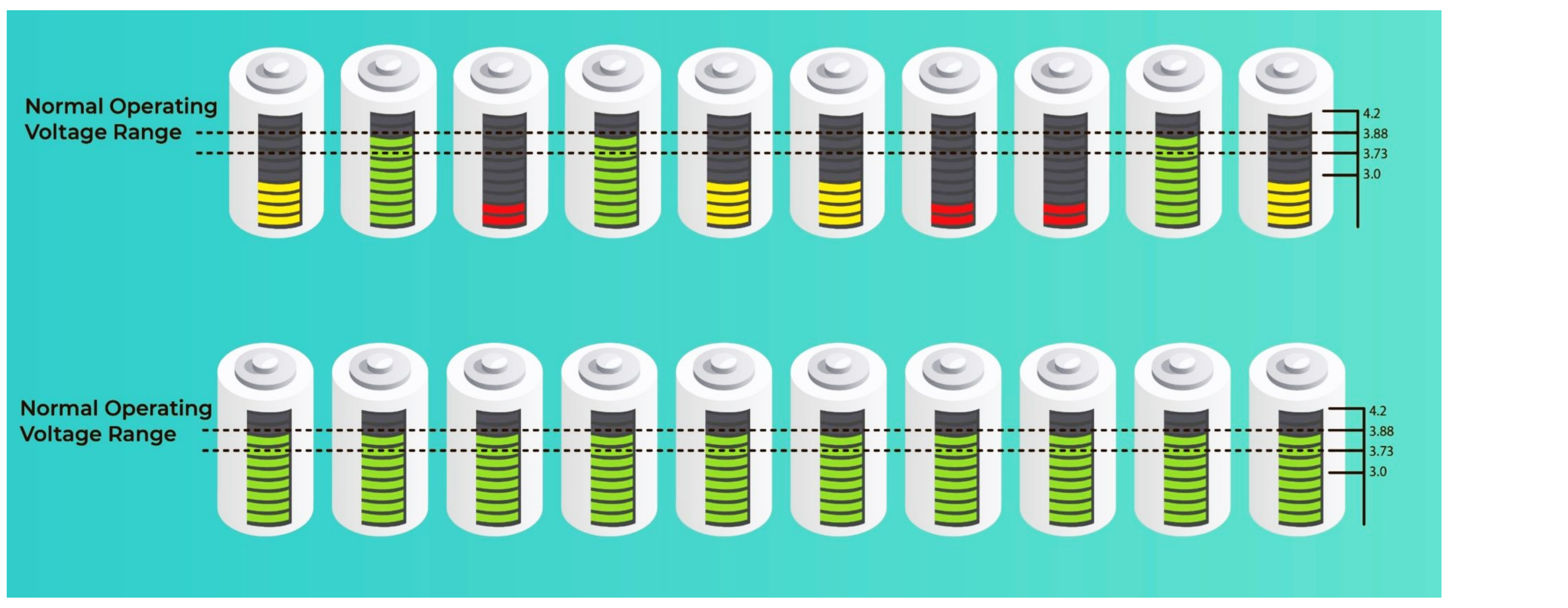

Figure 1: Mechanism of active balancing

RESULTS & DISCUSSION

Figure 3 shows the variation of voltages of a pack at the end of each characterisation cycle. The sudden increase (indicated by the **purple** arrow) is due to power fade. If the degradation cycle is continued, the increase is expected to grow exponentially. ΔV (indicated by the continuous **red** line) gradually decreases then remains almost constant. When SOC (State of Charge) decreases, internal resistance of cells increases. This is demonstrated by the decrease in vertical magnitude of ΔV along the ∂V/∂Q graph as shown in Figure 2.

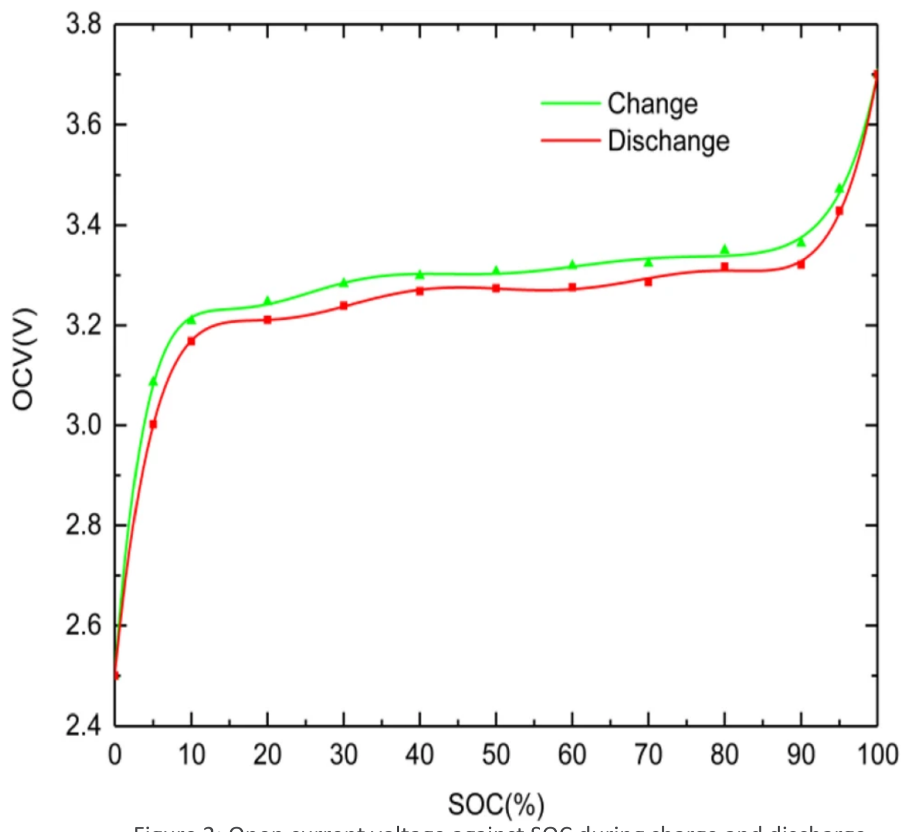

Figure 2: Open current voltage against SOC during charge and discharge

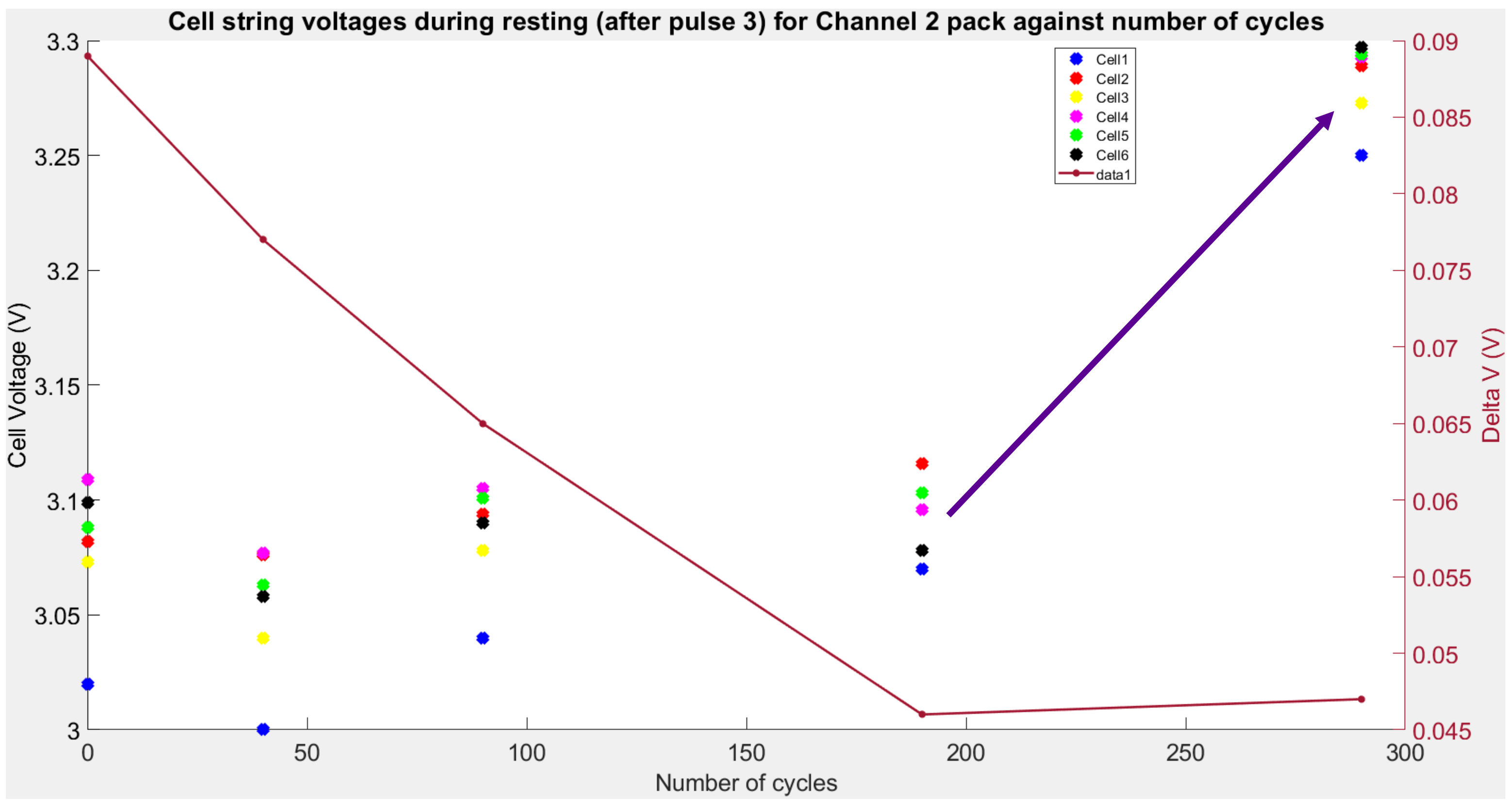

Figure 3: Voltage distribution at the end of characterisation against number of degradation cycles completed

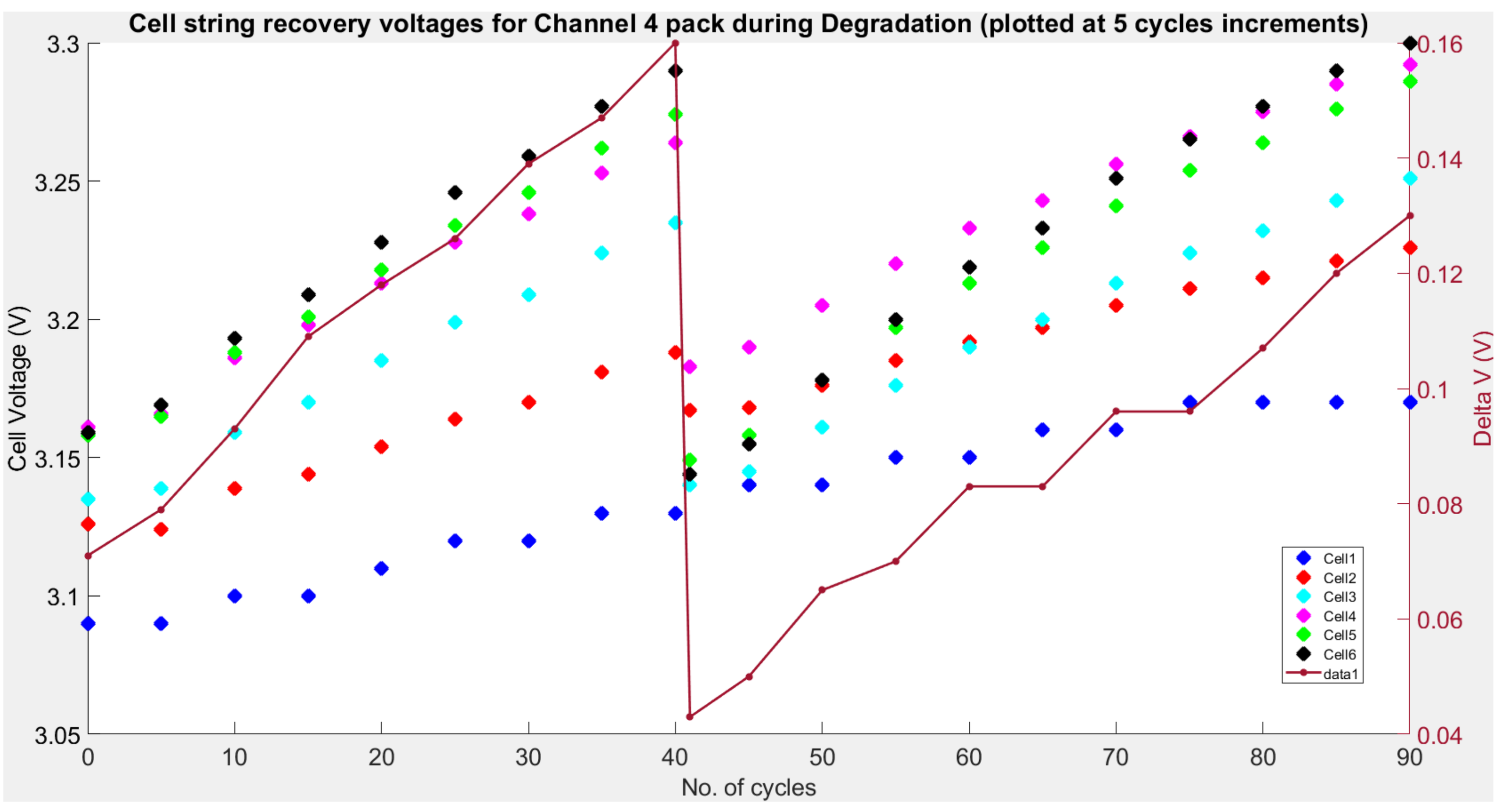

Figure 4: Degradation cycling recover voltage (in increments of 5 cycles) against number of cycles

Figure 4 shows the cell string recovery voltages against the number of cycles completed (in 5 cycle increments). The increase in ΔV (indicated by the continuous **red** line) is due to cell ageing and is minimal when balancing occurs after cycle 40. Had balancing not occurred, the range of recovery voltages would have kept increasing and less and less of the cell's voltage window would have been utilised. It is noticed that the cell string voltages swap positions with respect to each other during the cycling process after balancing. This phenomenon is consistent across the packs tested.

Figure 5 shows the difference of cell string voltages with respect to pack mean voltage during characterisation charging. The peaks seen are associated with incremental capacity analysis however, the reason for the swapping of cell voltages with respect to each other is undetermined.

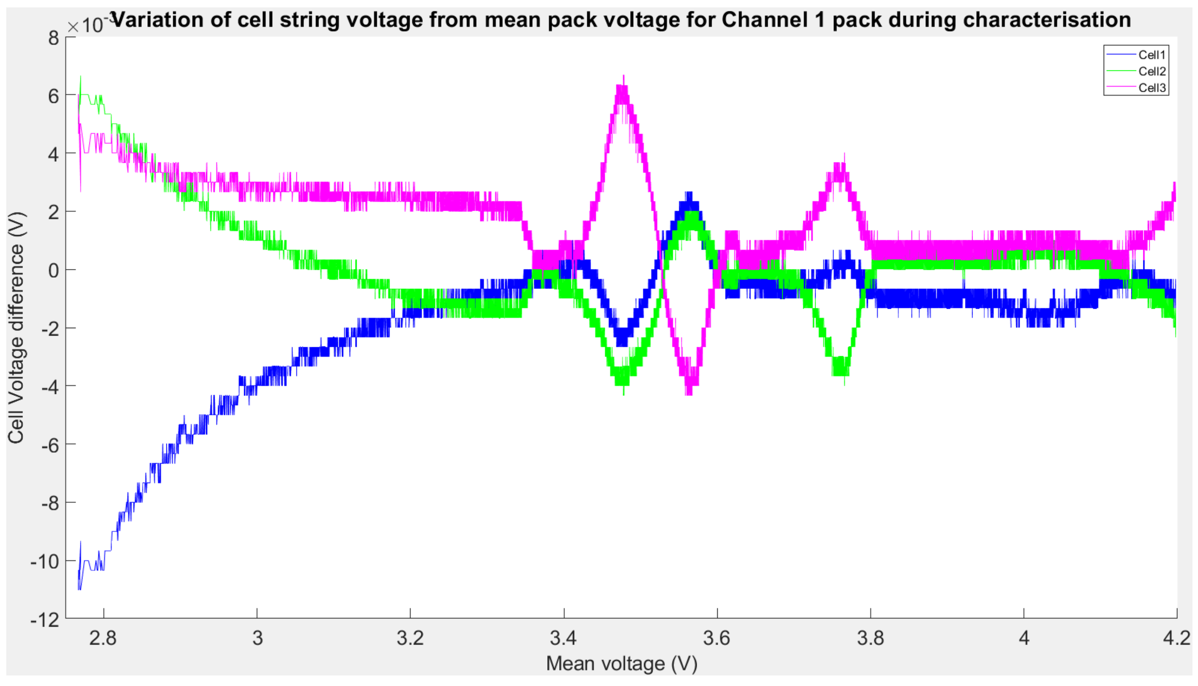

Figure 5: Voltage difference against mean pack voltage during characterisation charging

CONCLUSION

Balancing is necessary to utilise a pack's maximum voltage window. Preferential degradation does not occur on a particular cell string but rather the whole pack degrades almost equally. Voltage loss through hysteresis causes the packs to go out of balance quickly during cycling as the experiment is an accelerated simulation of actual pack degradation. This shows that the pack would benefit most from balancing during cycling. Although characterisation does balance the pack slightly, the effect of the cell going out of balance during cycling is more severe. Terminal cells are always cut the pack off at the voltage limits. Fluctuations of cell voltages during characterisation charging is associated to incremental capacity analysis but the reason for the swapping of voltages between each cell string is yet to be determined.

NEXT STEPS

- Rerun the old packs (from which the above analysis were obtained) on a **different** cycler
  - ✓ Check for consistency in results (if terminal cells continue to cut off at limits)
  - ✓ Hypothesise how balancing is conducted by a cycler and its effects on cell strings voltage distribution
- Build **new packs using different cells** than in old packs: Configurations of 6s 6p, 6s 2p and 12s 2p
  - ✓ Monitor how cell string voltage distribution varies with addition of parallel strings
  - ✓ Compare if a particular cell string voltage is consistently lower than the others during characterisation
  - ✓ Analyse the data from the 2p packs to form corelations with the old packs

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INTERN BIO

Yaashiene is in her final year of a MEng course in Mechanical Engineering at Imperial College London. She is interested in innovative engineering ideas in the **motorsports, automation** and **energy** sectors.

Yaashiene aspires to be a chief engineer in an engineering R&D sector that utilises the latest technologies. She is also passionate about designing sustainable solutions for the engineering problems faced by today's world.

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