HBM Prenscia Technology Day

Virtual Seminar Series

Experimental Analysis of Dynamic Charge Acceptance Test Conditions for HEV/EV Battery Cells

Presented by Dr. Matt Smith
Centre for Research into Electrical Energy Storage & Applications
University of Sheffield

Session #1: Electric Vehicle Battery Testing

Experimental Analysis of Dynamic Charge Acceptance Test Conditions for HEV/EV Battery Cells

Abstract

The presentation details the results of a series of tests to determine the Dynamic Charge Acceptance (DCA) performance of small form-factor carbon-enhanced VRLA cells designed for use in Hybrid Electric Vehicle (HEV) applications, together with standard lead-acid and lithium iron phosphate (LFP) cells. The results demonstrate how varying the conditions and parameters of the standard DCA test regime can provide a superior evaluation of DCA performance and lead to a better understanding of cell behaviour under real-world conditions. It also demonstrates the importance of recognising the limitations of existing test procedures and how they should be considered before using results from such tests to make judgements about real-world battery performance.

About the presenter, Dr. Matt Smith

Matthew Smith is a Research Associate in the Centre for Research into Electrical Energy Storage & Applications Group of the Electrical & Electronic Engineering Department at The University of Sheffield, UK. He graduated from the University of Sheffield with a Master’s Degree in Digital Electronics in 2014 and obtained his PhD from the University of Sheffield in 2018. His research interests include Power Electronics, Electrical Energy Storage & Management and Automotive Battery Performance. Specifically, his work examines factors affecting the lifetime of batteries within automotive and energy storage applications, battery testing methodologies and procedures, and the performance of automotive batteries in mild-hybrid applications.

Dynamic Charge Acceptance in Lead-Acid and Lithium-ion Cells

Performance Variation with Environmental Conditions and Test Parameters

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CREESA

The Centre for Research into Electrical Energy Storage and Applications (CREESA) is one of the UK's leading research centers on all aspects of electrical energy storage.

2MW / 1MWh grid-connected research battery system and 500kW / 10kWh grid-connected flywheel system.

Ability to laboratory test battery systems from cell level to full EV packs.

Experience of all aspects of energy storage: testing, modelling, performance analysis, etc.

DCA & Standard Test Procedure

Project origins

Advanced Diesel Electric Powertrain (ADEPT) project to create a mild hybrid vehicle with an advanced 48V lead-acid battery system.

Vehicle fitted with multiple novel electrification technologies to reduce auxiliary load on IC engine.

Battery charging performance is crucial to overall vehicle performance in HEV applications.

ADEPT
Advanced Diesel Electric Powertrain

What is DCA?

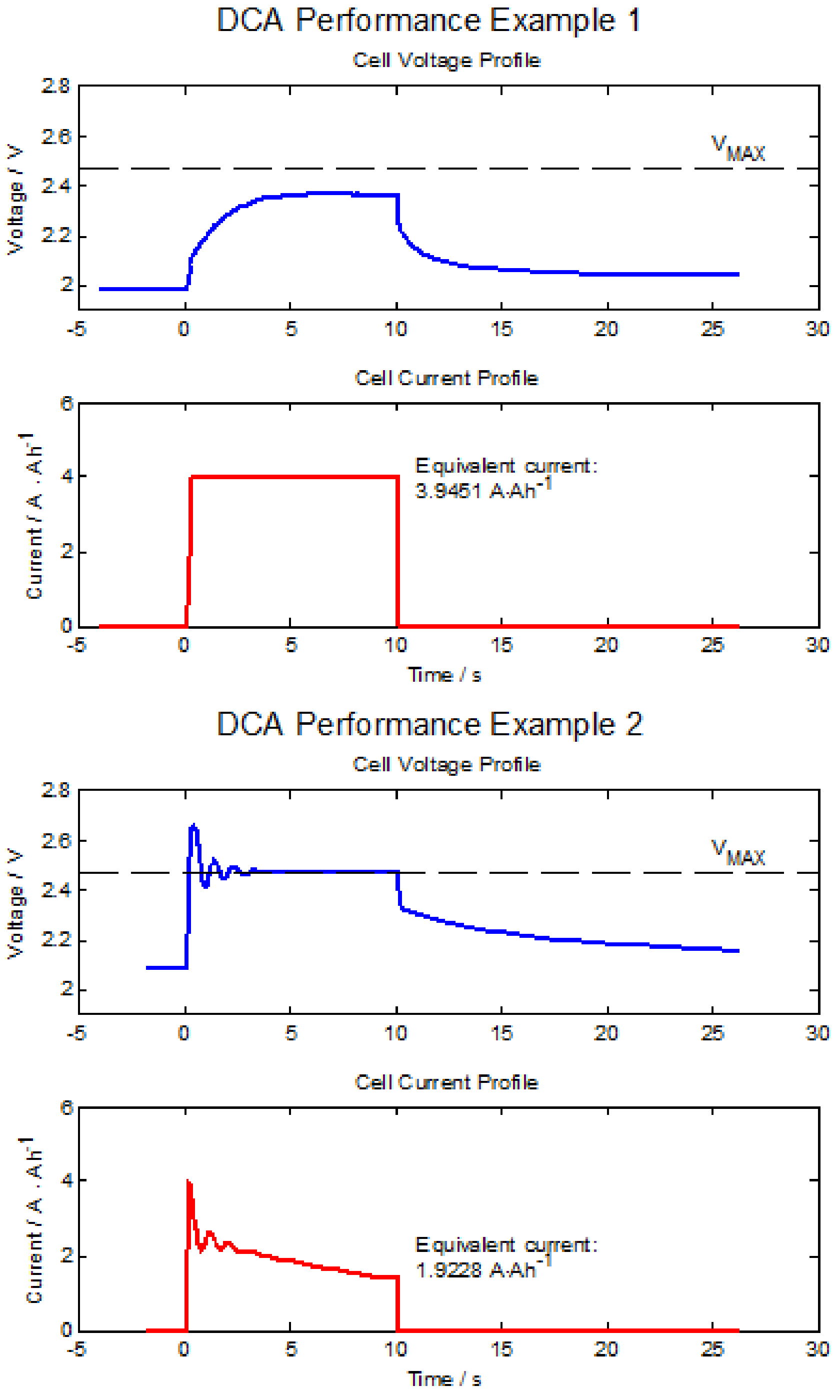
The ability of a battery to accept instantaneous energy during charging.

Generally taken to cover high current, short-duration recharge pulses.

Limited primarily by maximum terminal voltage of the battery.

Expressed in terms of equivalent charge (recuperation) current, I_{recu}, for the period of the pulse, normalised to the capacity of the battery.

Units of $A \cdot Ah^{-1}$ or 'C'.

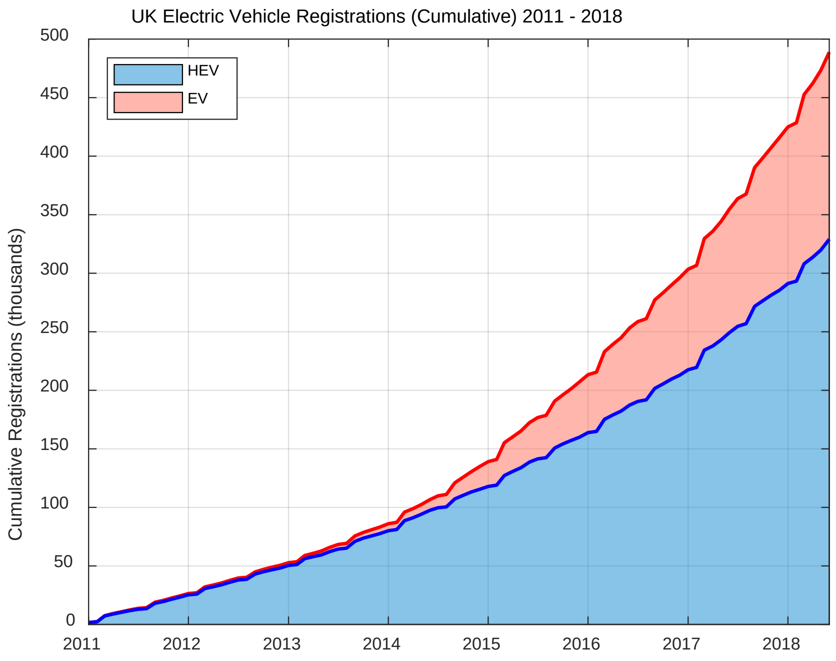


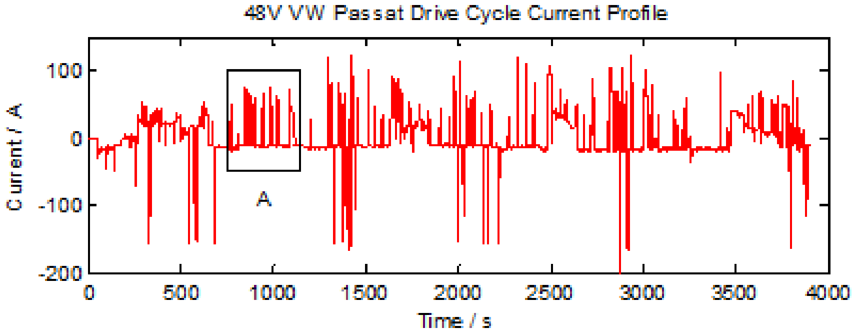
Why does DCA matter?

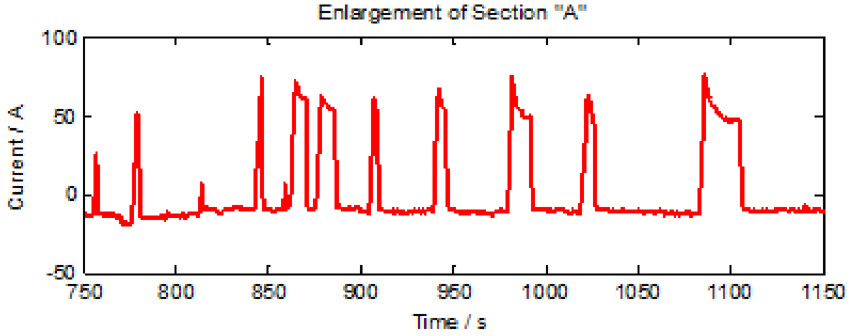
Important factor governing the performance of EV batteries, particularly those of hybrid vehicles.

Short-duration, high-current charge pulses are characteristic of HEVs with regenerative braking.

Increasing uptake of EVs, of which the majority are hybrid vehicles.







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How is DCA determined?

Standard method for automotive batteries defined by EN50342-6 ‘DCA Short Test Specification A3’.

- Pre-test conditioning
- Full discharge
- Recharge to 80% SoC
- 1st DCA Pulse Profile (DCAPP)
- Charge to 100% SoC
- Discharge to 90% SoC
- 2nd DCAPP

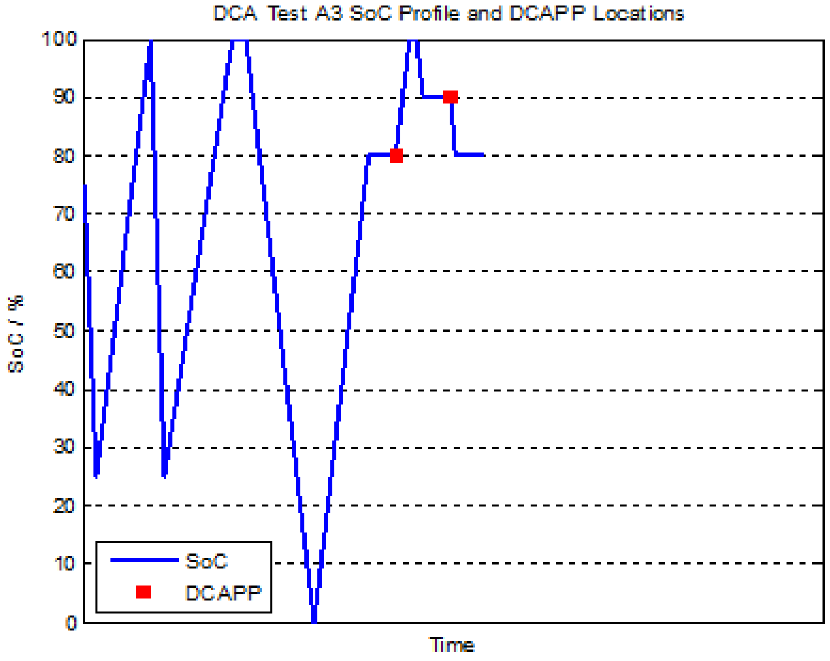
DCAPP consists of 20 microcycles (A-E) applied sequentially.

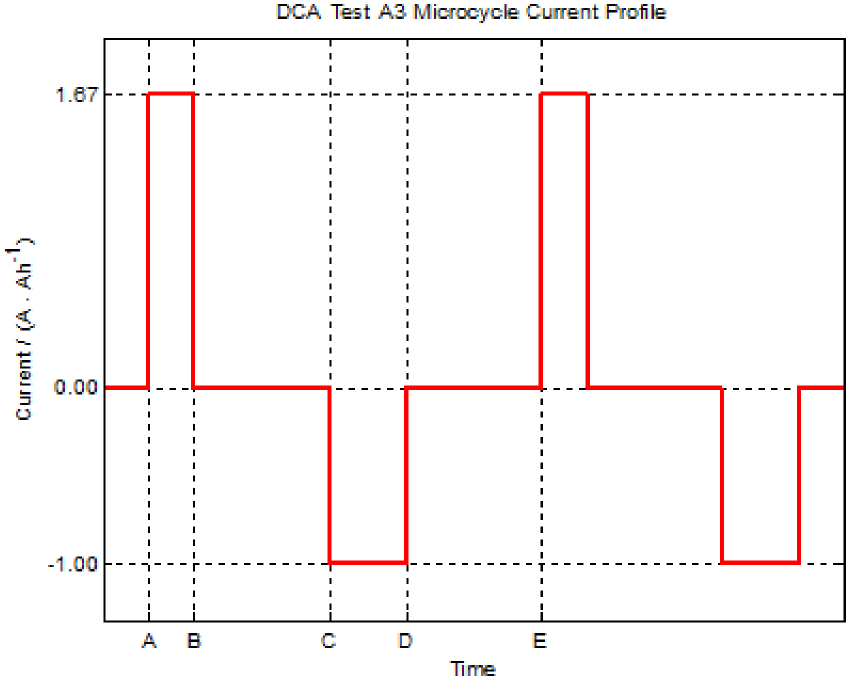
10 second charge pulse (A-B).

30 second rest period (B-C & D-E).

Microcycles are charge balanced, $\int_A^B I(t)dt = -\int_C^D I(t)dt$.

Ambient temperature maintained at 25° C throughout.





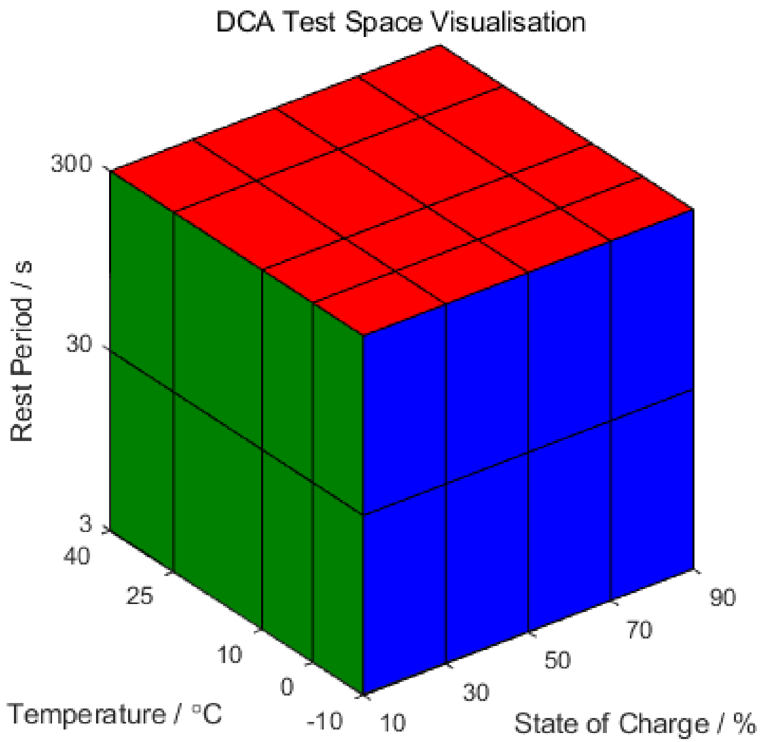
Areas of Investigation & Test Procedure

Areas of Investigation

- Examine the effect on DCA performance due to variations in the test parameters and environmental conditions
  - State of Charge
  - Charge History
  - Rest period within DCAPP
  - Ambient temperature

Areas of Investigation

- 3-dimentional ‘test space’
- DCA performance examinable against combinations of variables



Test Cells

Cells specifically designed for HEV applications and are optimised for HRPSoC performance.

Specifications

Manufacturer: Banner GmbH

Nominal Voltage: 2 V

Capacity: 6 Ah

Chemistry: Carbon-Enhanced VRLA

Test Procedure - Microcycle Profile

Adapted from A3 method.

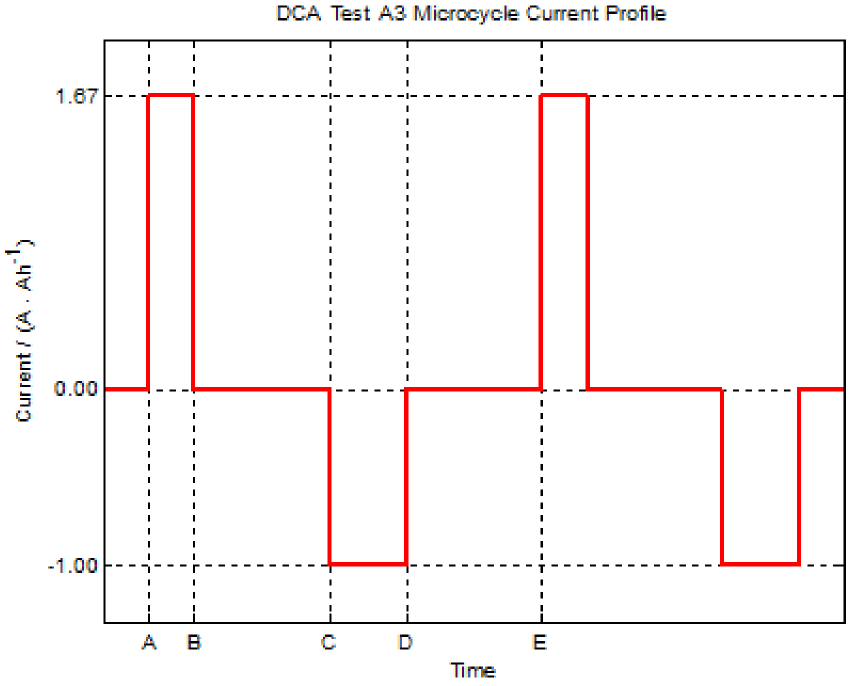
Applied charge current increased to 4.0 $A \cdot Ah^{-1}$.

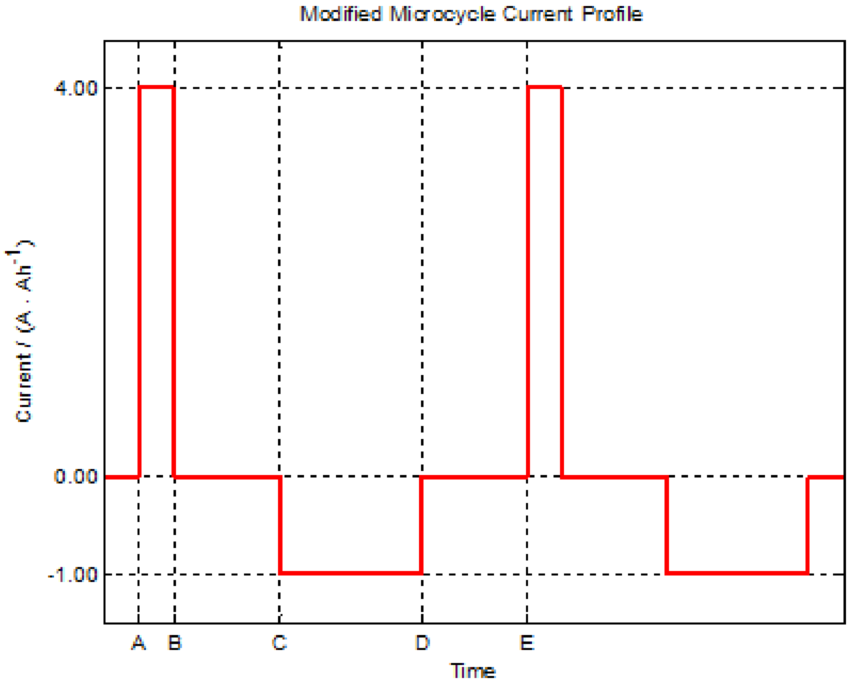
Current increased to allow better analysis of battery performance under HRPSoC conditions typical of HEVs.

Cycle remains charge balanced to avoid SoC-drift during DCAPP.

Variable rest period (B-C & D-E) introduced of either 300, 30 or 3s.

Rest period remains constant for complete DCAPP.





Test Procedure - SoC Profile

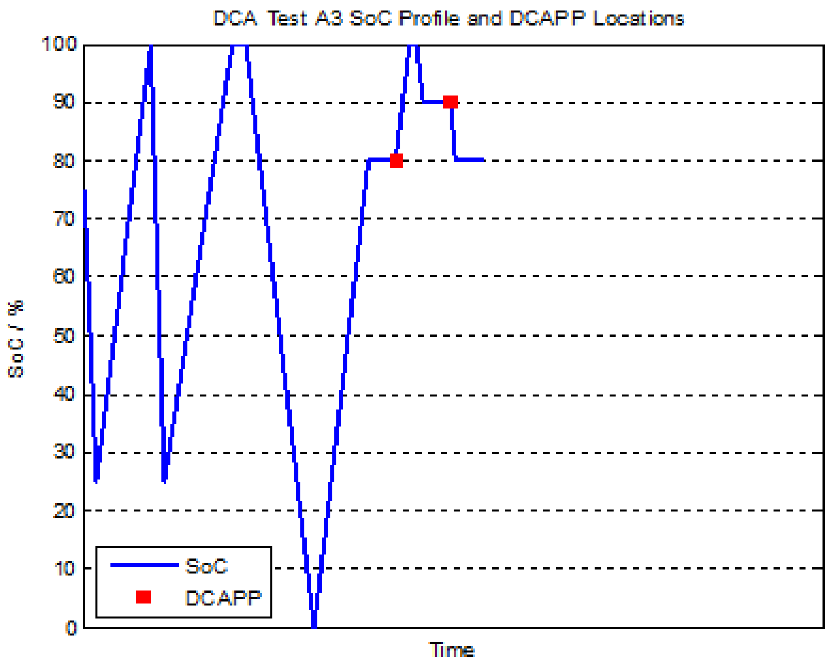
Adapted from A3 method.

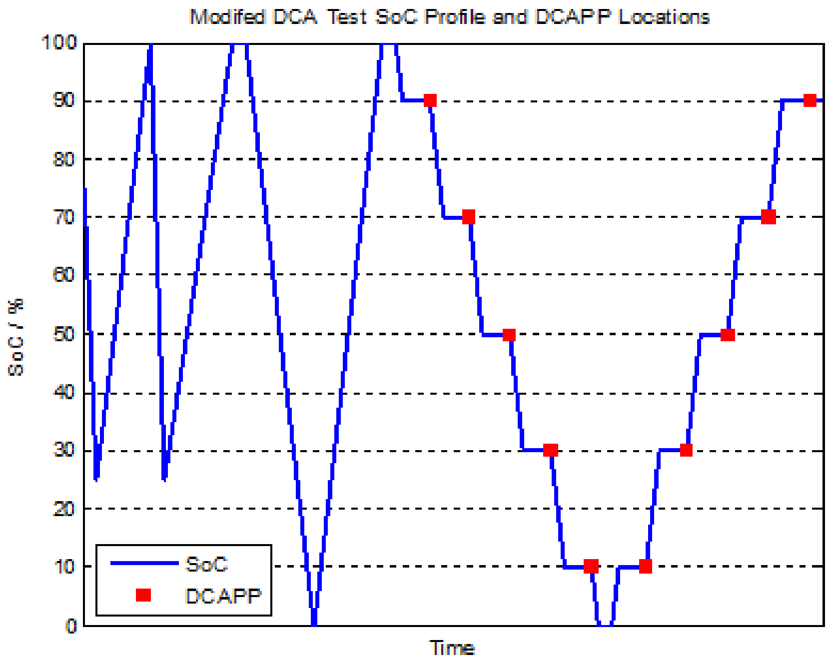
Pre-test conditioning and capacity determination as with A3 method.

Profile extended to measure DCA performance across a wider range of SoC – 10, 30, 50, 70 % 90%. This is more typical of real-world HEV operating conditions.

Gives greater insight into DCA performance with respect to charge history. Also allows for analysis of the effect of charge history at common SoC levels.

Ambient temperature and DCAPP rest period remains constant for complete test profile.





Test Procedure - Temperature

Ambient temperature varied to asses DCA performance across a range of real-world temperatures.

Temperatures investigated:
-10, 0 10, 25, 40°C

Cells tested in free air in environmentally-controlled chambers for duration of test.

Thermocouples attached to cell exterior to measure temperature.

Results & Conclusions

Variation with SoC & Charge History

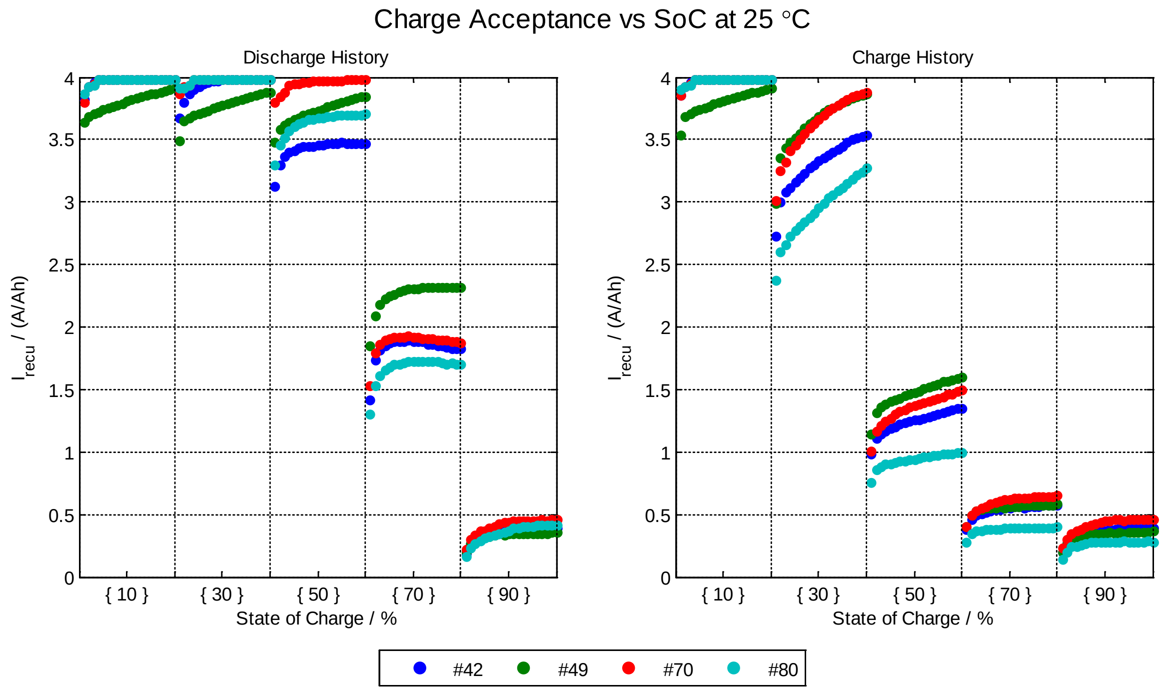
Good correlation between results from the four test cells.

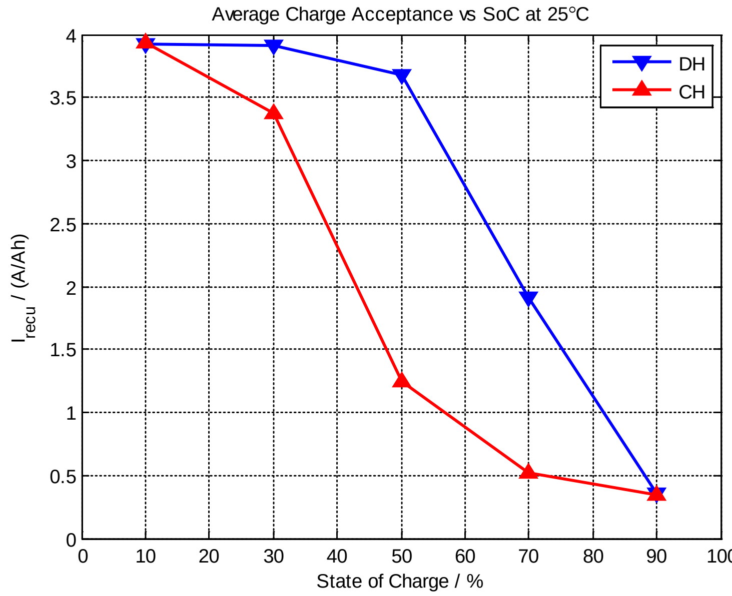
Significant influence of SoC on DCA performance when analysed across the SoC range. DCA is dramatically improved as SoC is reduced.

Charge history also has a large influence on DCA performance, cells perform better when they have discharge history.

This hysteresis effect can be observed from the average charge acceptance response.

Charge history also influences the shape of the performance within the DCAPP.





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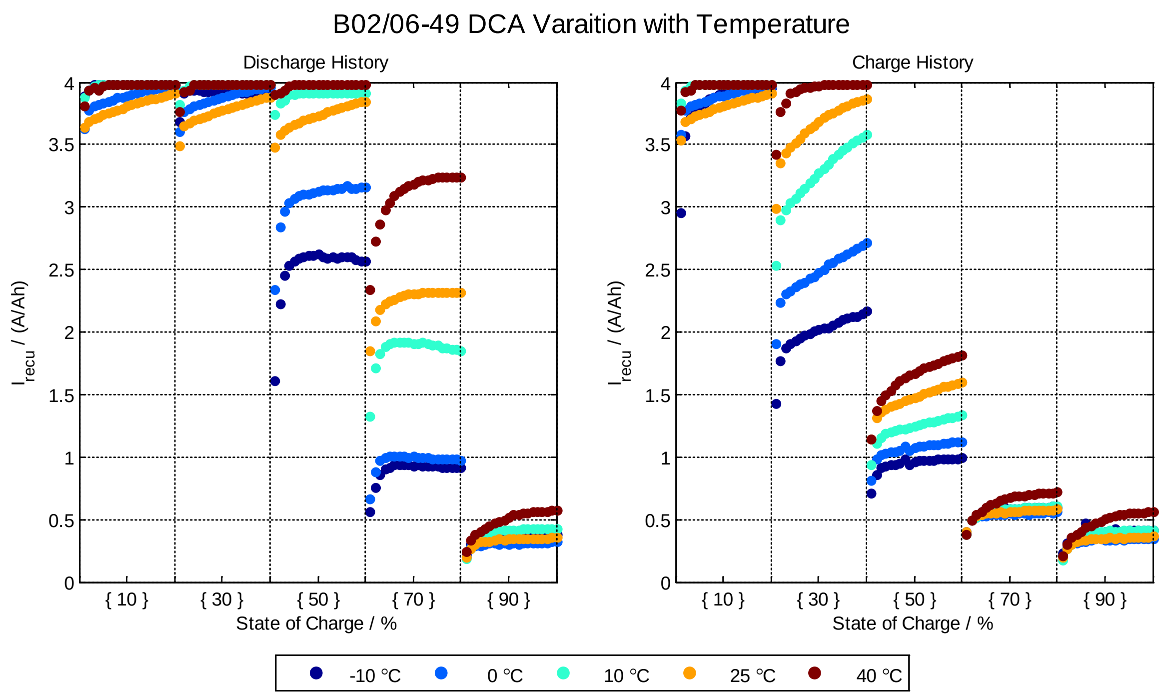
Variation with Temperature

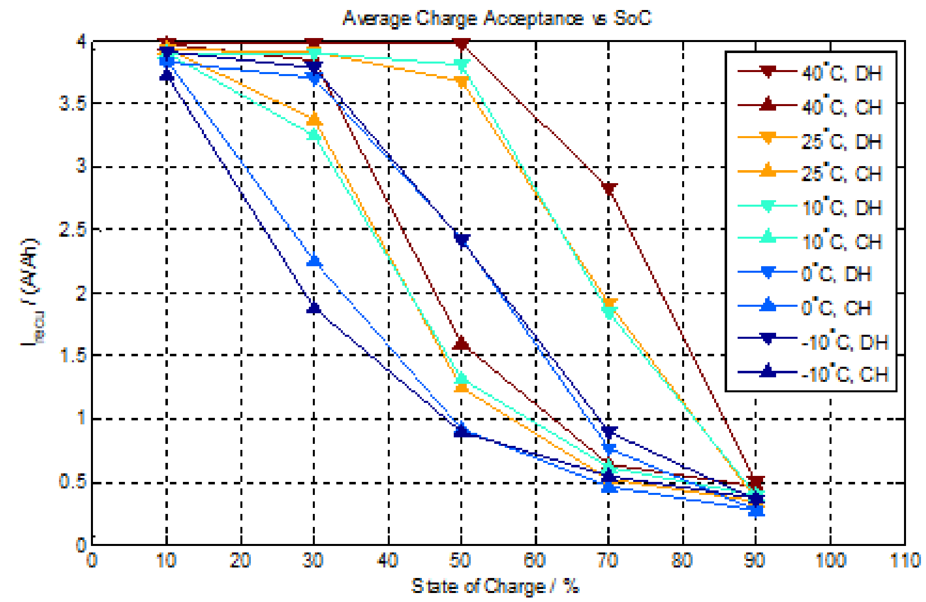
Results show profound effect of ambient temperature on DCA performance, this is particularly noticeable in the middle of the SoC range.

Between 30 & 70% SoC, DCA is significantly reduced as temperatures decrease.

Little difference is apparent between the results of cells tested at 0 & -10° C.

From the average charge acceptance it can be seen that the hysteresis effect of charge history can be seen to be equivalent to that of a temperature change.





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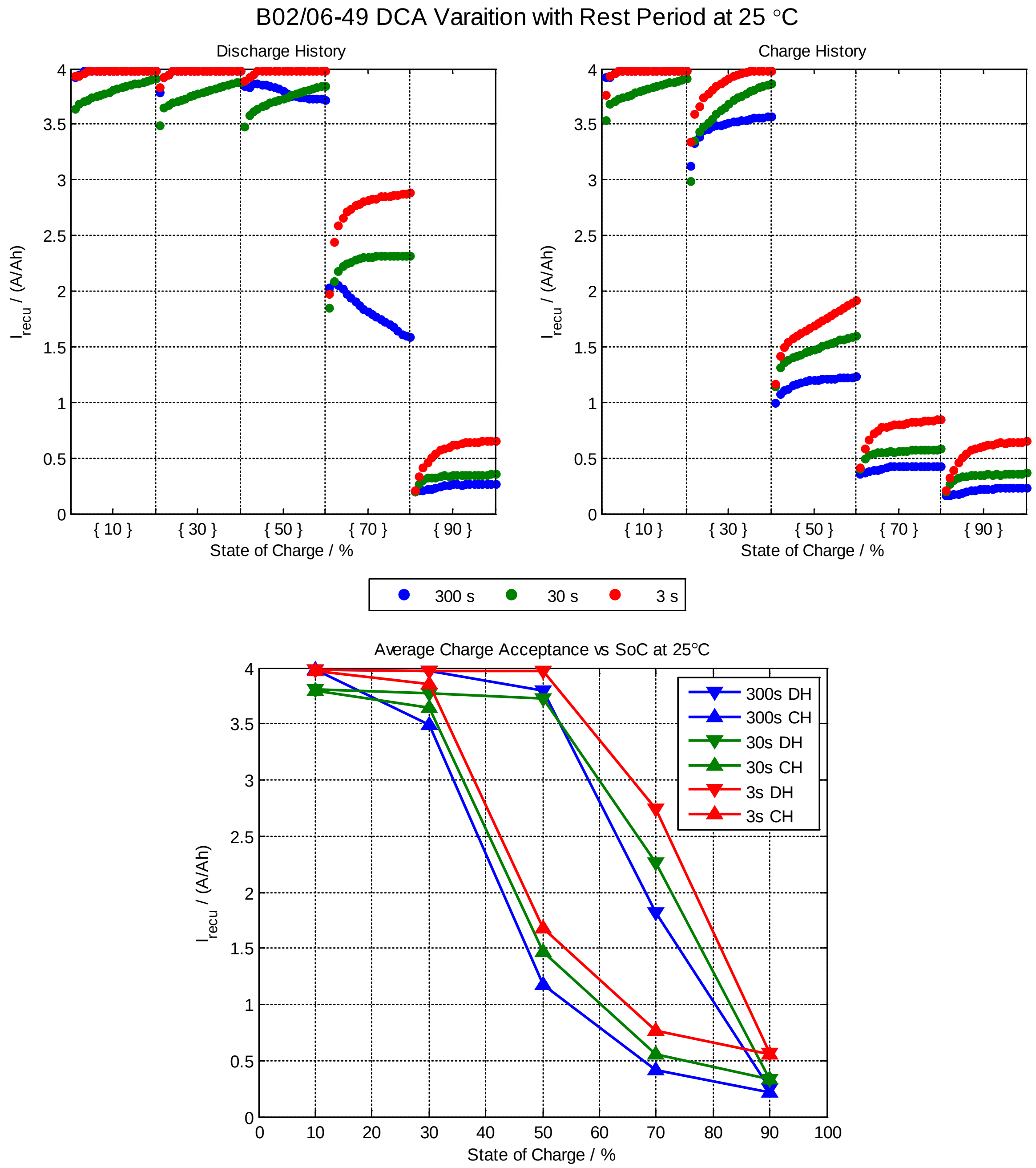
Variation with Rest Period

Rest period within the DCAPP has an impact on DCA performance.

Unlike temperature, the effect of rest period variation is seen uniformly across the SoC range.

The effect is also much more consistent with respect to charge history.

In the majority of cases a reduced rest period improves DCA performance.



Comparison with Standard Lead -Acid

For comparison and validation the same test procedure was applied to a standard 2V VRLA cell.

Specifications

Manufacturer: EnerSys

Model: Cyclon 0810-0004

Nominal Voltage: 2 V

Capacity: 2.5 Ah

Chemistry: VRLA

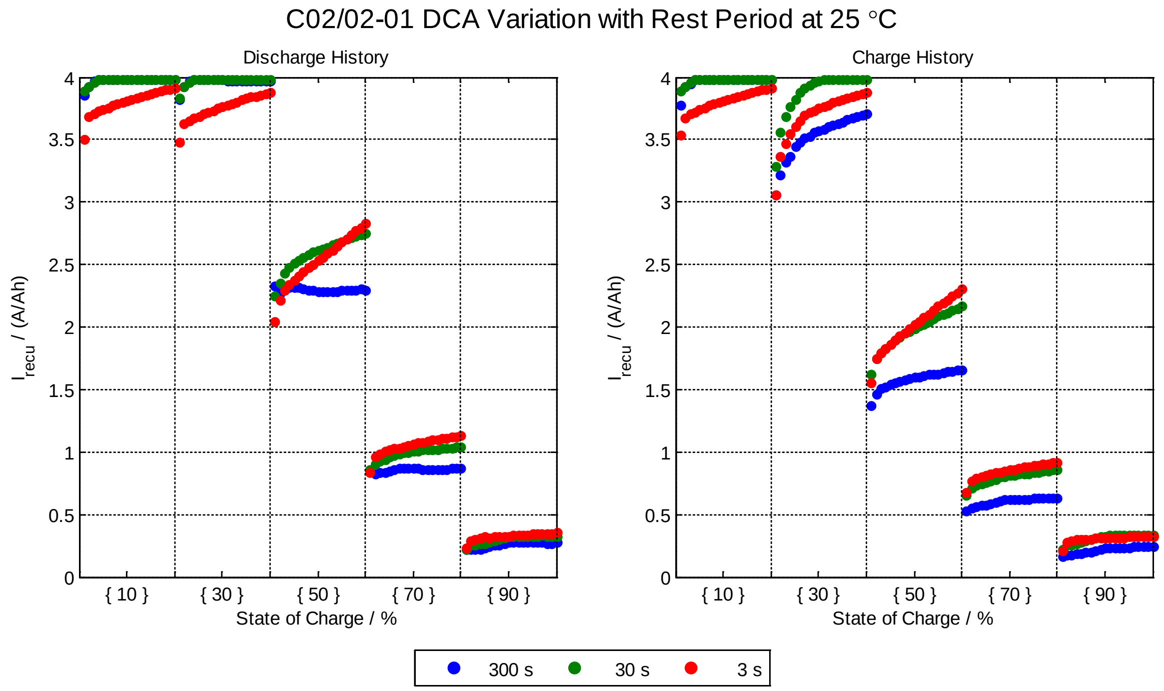
Temperature variation not considered for comparison testing.

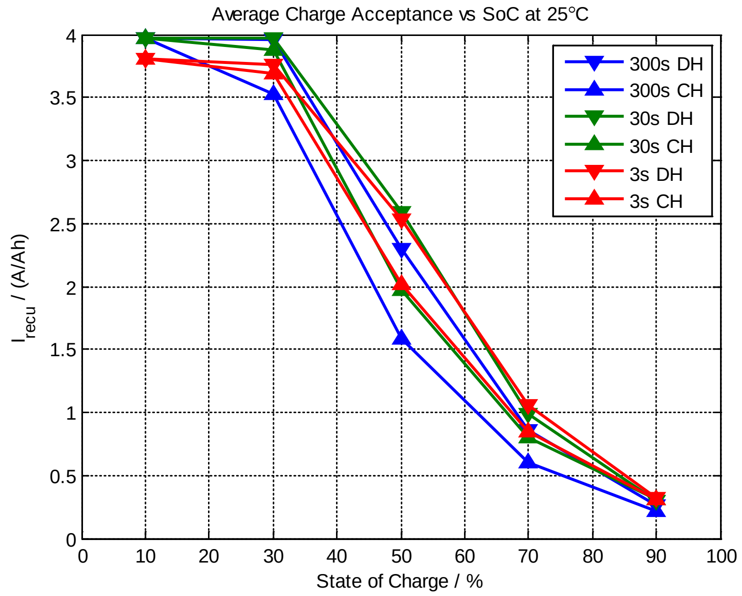
Results for Standard Lead -Acid

Results broadly agree, trends previously identified are present. DCA is seen to be improved at lower SoC and with shorter rest periods.

The effects of charge history are much reduced, DCA performance is more consistent with respect to charge history.

The trade-off for this consistency is that the performance is poorer than that of Carbon-Enhanced Lead with discharge history.





Comparison with Lithium-ion

For comparison and validation the same test procedure was also applied to a lithium iron phosphate cell.

Specifications

Manufacturer: ENIX

Model: ACL9012

Nominal Voltage: 3.2 V

Capacity: 3.3 Ah

Chemistry: $LiFePO_4$

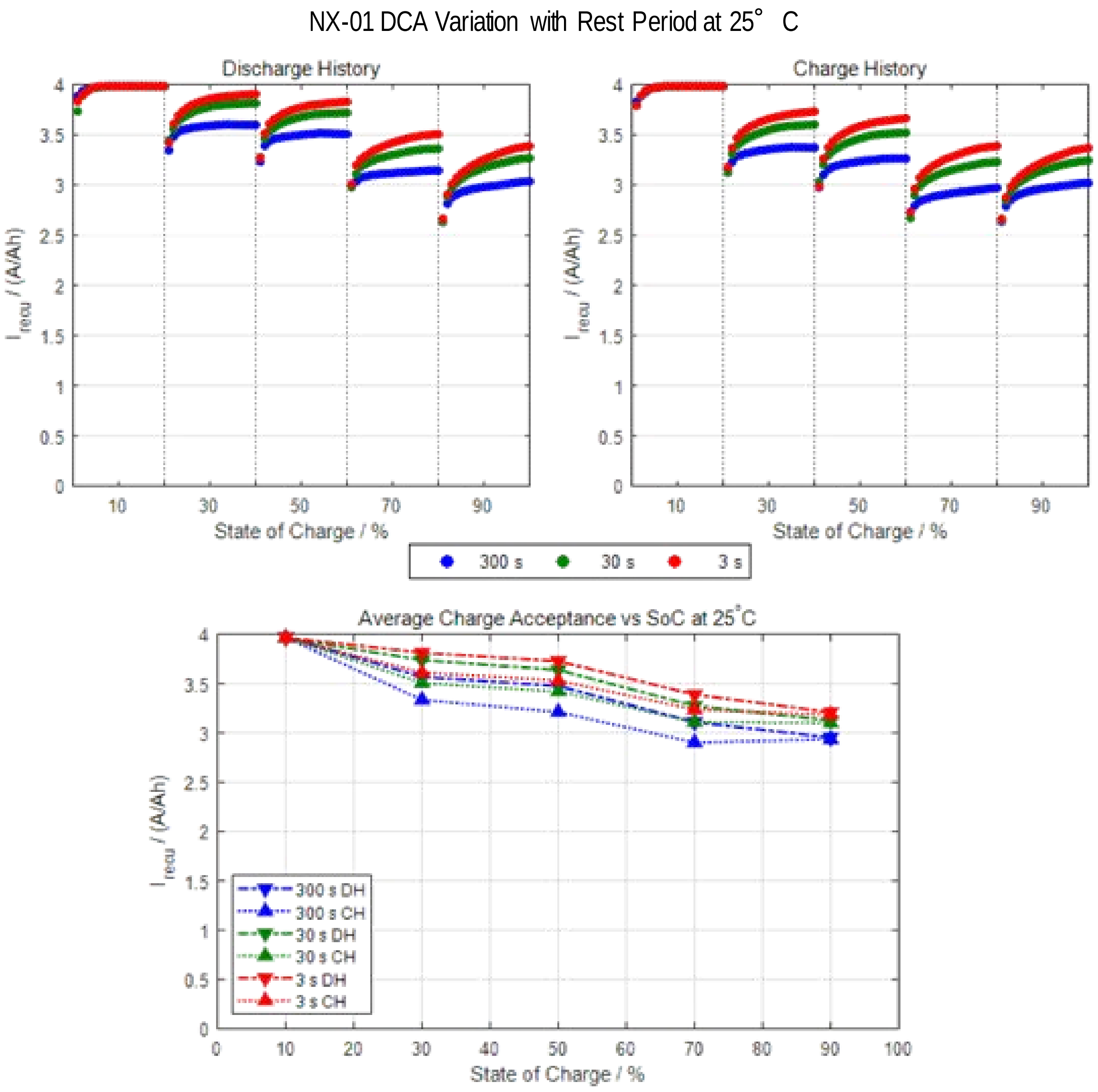
Temperature variation not considered for comparison testing.

Results for $LiFePO_4$

The effects of charge history are reduced significantly, DCA performance is virtually independent of charge history.

The effect of SoC is also much reduced, with very little difference in DCA performance between 90 and 30% SoC.

Improved consistency of performance comes at cost of absolute DCA performace al low SoC, where lead is seen to perform better.



Conclusions

- DCA performance is not static
  - Improves at lower SoC
  - Improves at higher temperatures
  - Improves with reduced Rest Period
- Carbon-enhancement affects performance
  - Primarily influences charge history behaviour
  - Standard lead shows broadly consistent performance
  - CE improves performance with discharge history
- Lithium cells show increased consistency
  - Consistency comes at cost of lower charge acceptance at lowSoC

Conclusions

- Standard DCA test procedure does not reveal this information
  - Crucial to recognise objectives and limitations of test procedures
  - Many procedures are only designed to be comparative
  - Where performance is critical, testing with real -world data should be considered

With thanks

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Thank you for your attention…

QUESTIONS?

Q&A

- Muhammad Afzal (Omnicell, USA)
  - What precaution must be taken in manufacturing of Li Batteries to be safe for its life?
    - *This doesn't directly relate to my research, and I'm not all too familiar with the specifics of the manufacturing process. Anecdotally, however, we have tested many hundreds of lithium cells during my time at CREESA, and I have only known a handful to fail from manufacturing defects when used within their design parameters, so I would suggest that the current manufacturing techniques are effective in ensuring the cell is as safe as reasonably practicable when it leaves the factory. As you would expect, failures are far more common when cells are pushed beyond their specified limits, so to ensure lifetime safety really comes down to providing a reliable and effective Battery Management System alongside the lithium battery to protect the cells against misuse or abuse in service.*
  - Does battery life follow a Weibull Distribution? – if so what is the typical B10 life for Li EV Batteries?
    - *I don't know about this, it's not something we have investigated.*

- Sezer Kiral (Havelsan, Turkey)
  - How should we measure the general health of batteries? - endurance dropped down 4 hours from 5 hours running in the field with unmanned ground vehicle. This is needed to define the change period of batteries, for lifetime information.
    - *This really is the holy-grail of battery research, and at the moment we don't really have a method which is practical in all applications. The simplest method is to perform a capacity test on the battery, this can then be compared to the datasheet capacity which will give an estimate of the amount of health the battery has lost. Such a method is rarely practical in the real-world, however. There is much research being performed on mathematical models to estimate capacity loss and aging, these often require capturing data at very high rates, or significant processing power to compute the result, which again is a potential problem in practical applications.*

Q&A

- Prashant Tripathi (Mahindra Electric Mobility Limited, India)
  - What Dynamic (DCA) test should be done on battery pack or on cell, to capture 8 years of vehicle life?
    - *Significant ageing of the cells is likely to occur over 8 years, so this must be considered. It is possible to perform accelerated aging tests on cells, by repeatedly cycling them. This is something we have investigated with DCA in lead-acid cells, the results of this work have been published as conference proceedings and are available here: "An Experimental Analysis of the Effect of Cell Degradation on Dynamic Charge Acceptance in Lead-Acid Cells" (ISIE 2018), DOI: 10.1109/ISIE.2018.8433780*

- Diego Tobon (Alstom, France)
  - I see that you have compared Lead-Acid with Lithium-ion cells, do you have any experience with NiCD cells
    - *We have not investigated the effects of DCA on NiCD cells, so I can't offer any comparisons of their performance.*

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