A TWO-LAYER MODEL PREDICTIVE CONTROL FOR HYBRID BALANCING SYSTEMS ABLE TO MANAGE CAPACITY, TEMPERATURE, STRESS, AND LOSSES

R. de Castro[1], H. Pereira[2], **J. Varela Barreras**[3], R. E. Araújo[2], H. C. Pangborn[4]

[1] Dep. of Mechanical Engineering, University of California Merced, US
[2] Faculty of Engineering, University of Porto, and INESC TEC, Portugal
[3] Dep. of Mechanical Engineering, Imperial College London, UK
[4] Dep. of Mechanical Engineering, Penn State University, US

INTRODUCTION

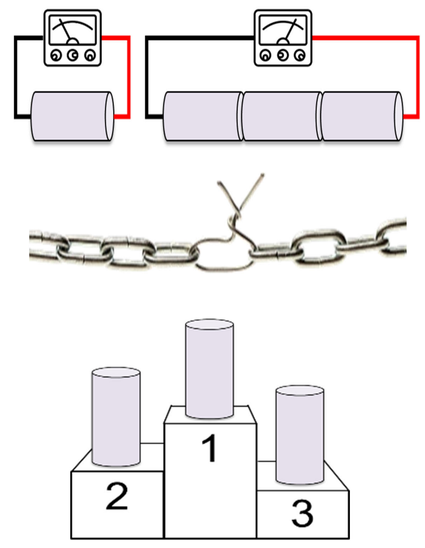
This study deals with the design, simulation and validation of an online control strategy for a hybrid balancing systems (HBS), an emerging concept that joins cell level battery equalization and hybridization with supercapacitors (SCs), aiming to reduce cell-to-cell variations, increase battery power capability, and prolong battery lifetime. To control this system, we develop and implement a new two-layer model predictive control (MPC) framework. [1]

MOTIVATION: CELL-TO-CELL DIFFERENCES

The series connection of cells in a pack, like in any chain, means that performance is limited by the weakest cell in terms of power or energy. If the cells were identical, this would not be a problem.

Unfortunately, there are cell-to-cell variations, which may increase over time, leading to limited capacity and power, uneven temperature distributions, and shorter lifetime.

The automotive industry overcomes this problem by oversizing the battery, running cell screening and selection procedures, parallelizing cells, improving thermal management and adopting so-called passive balancing systems. However, each of these solutions has shortcomings. [2]



THE HYBRID BALANCING SYSTEM SOLUTION

Recently, a new gen of active balancing systems that offer more control features than state-of-charge (SoC) equalization have been proposed. Hybrid balancing systems (HBS) combine cell-level active balancing and hybridization, and maximize useful capacity (q), reduce and balance temperature (T), and minimize battery stress (S) and losses (L) (i.e. qTSL control). [1]-[3]

NEW CONTROL: TWO-LAYER MPC QTSL FOR HBS

The first layer determines the optimal SoC ref for the SCs considering long load forecasts and simple pack-level models.

The second MPC layer tracks this reference and performs charge and temperature equalization, employing more complex module-level battery models and short load forecasts.

This division of control tasks into two layers, running at different time scales and model complexities, enables us to reduce computational effort with negligible performance loss.

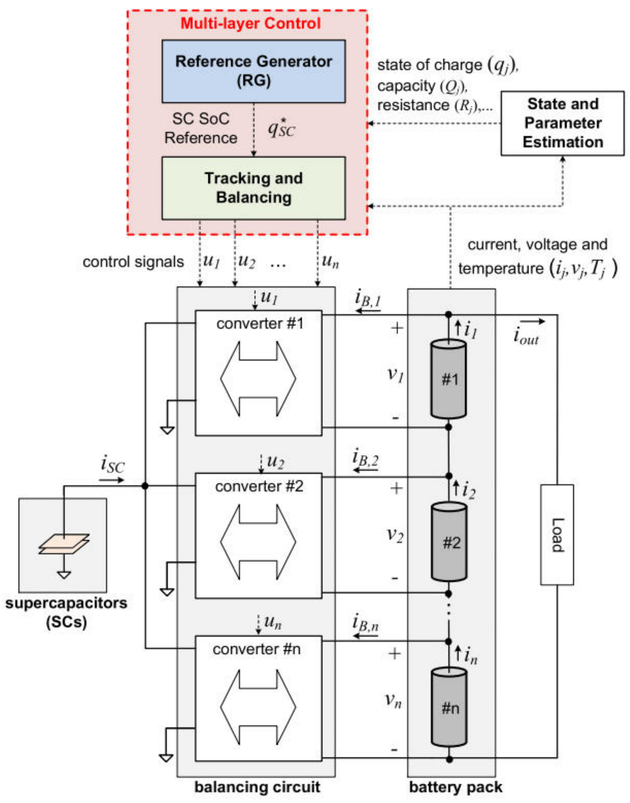
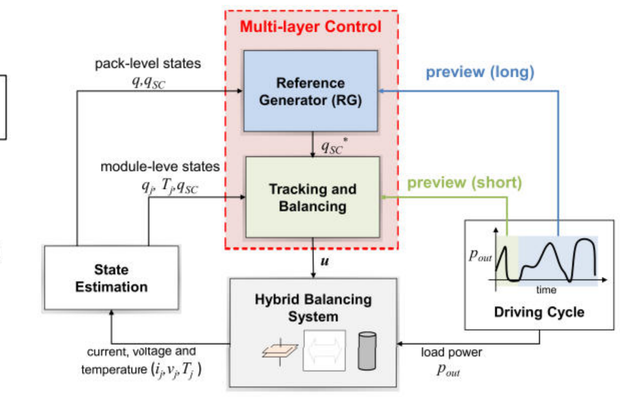
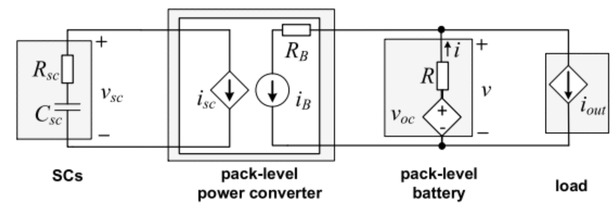


Diagram of the HBS and 2-layer MPC qSTL

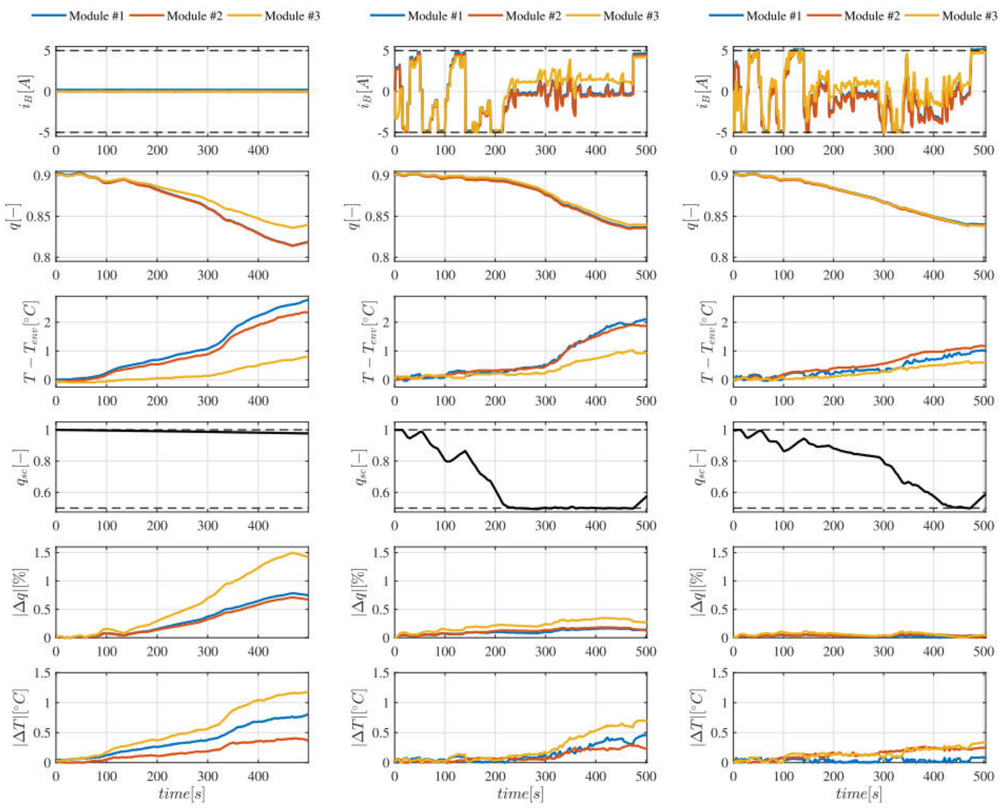


Two prediction horizons for load forecast



Pack model of the HBS used in the RG

EXPERIMENTAL RESULTS FROM SMALL-SCALE PROTOTYPE



NO CONTROL (BATTERY-ONLY)	ONE-LAYER MPC WITH A SHORT HORIZON (10 s)	TWO-LAYER MPC WITH SHORT (10 s) AND LONG (200 s) HORIZONS

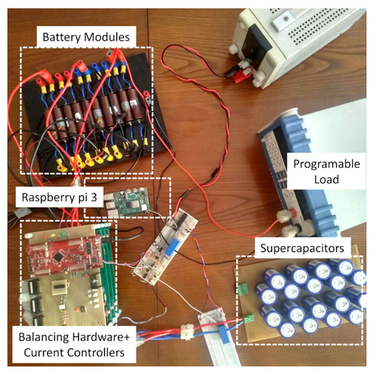
In comparison with *No Control*, the *2-layer MPC* reduces:

- SoC imbalance., $|\Delta q|$, -91%
- Current stress (-28%) & aging rate (-7%) in *'faulty'* modules (#1, #2)
- Temp. imbalance, $|\Delta T|$, -70%
- Max. temp., $T - T_{env}$, -57%
- Current stress (−12%) in 'healthy' module (#3)

Better results for 2-layer vs 1-layer MPC thanks to better overall utilisation of SCs energy.

SMALL-SCALE PROTOTYPE IMPLEMENTATION

- SCs Maxwell BCAP0310 P270 T10 (2S3P)
- Li-ion NMC cells (LG 18650HG2) in 3 modules in series: #1 & #2 as 3P (*'faulty'*), #3 as 4P (*'healthy'*)
- Balancing circuits: dual half-bridge
- Converters control: TI TMS320F28377S µC
- MPC implemented on Raspberry pi 3
- Optimization solved using Gekko Toolbox3



CONCLUSIONS: EFFECTIVE & PRACTICAL CONTROL FRAMEWORK

- Able to optimize multiple objectives (qTSL) while enforcing state and current constraints and exploiting load forecast information
- Tuning efforts are required, but practical guidelines provided in [1]
- Computation effort reduced thanks to various model complexities and time scales, but good performance
- Future work: large-scale implementation and improve the computational efficiency of tracking layer

REFERENCES

1. R. de Castro, H. Pereira, R. E. Araujo, J. V. Barreras, H. C. Pangborn, "qTSL: a Multi-Layer Control Framework for Managing Capacity, Temperature, Stress and Losses in Hybrid Balancing Systems," IEEE Trans. on Control Systems Technology, 2021.
2. R. de Castro, C. Pinto, J. V. Barreras, R. E. Araujo, D. A. Howey, "Smart and hybrid balancing system: design, modeling, and experimental demonstration," IEEE Trans. on Vehicular Technology, 2019.
3. J. V. Barreras, C. Pinto, R. de Castro et al., "Multi-Objective Control of Balancing Systems for Li-Ion Battery Packs: A Paradigm Shift?," 2014 IEEE Vehicle Power and Propulsion Conference (VPPC), Coimbra, 2014.

BIO: JORGE VARELA BARRERAS

Jorge combines an academic role at Imperial College London with an industrial role at CTAG. Previously, he was a postdoc at Oxford and PhD fellow at Aalborg.

+30 peer-reviewed articles and +10 years of R&D experience in ~20 projects with a budget +£100M.

His interests are around batteries in e-mobility and BESS.

FOLLOW ME
@jvbarreras

Jorge's work was kindly supported by the EPSRC Faraday Institution Multi-Scale Modelling Project (EP/S003053/1, grant number FIRG003).