State of Health Battery Estimator Enabling Degradation Diagnosis

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Introduction

Battery state of health (SOH) estimation is a complex yet essential process in the operation of reliable energy storage systems.

SOH estimation remains difficult and challenging primarily because battery degradation is **path dependent**. In order to take this complexity into account, many authors proposed to use **adaptive models** (accurate but calculation intensive and training) or **experimental techniques** (no training but less accurate and costly).

Advanced SOH estimation methodologies should have the advantages from both adaptive and experimental approaches: **be performed operando and be able to identify degradation symptoms from typical battery response while maintaining low computational complexity.**

In this work, we propose the basic principles for an SOH estimator that is light enough in calculation to be embedded while being able **to diagnose, in principles, any degradation scenario**.
The methodology is chemistry agnostic and will be applicable to Li-ion, Na-ion and any other chemistries relying on intercalation.

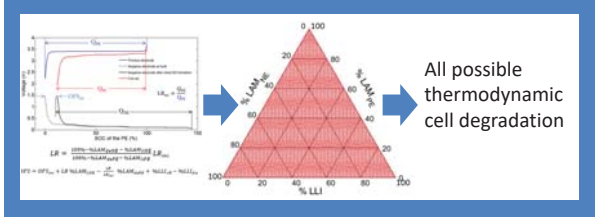
Proposed SOH estimator

Based on electrochemical voltage spectroscopies

+ direct measurement of voltage, light in computation, and accurate diagnosis & prognosis.
- lack the adaptability of computational intensive methods.

Problem: matching observable voltage changes with degradation mechanisms since materials react differently to similar aging.

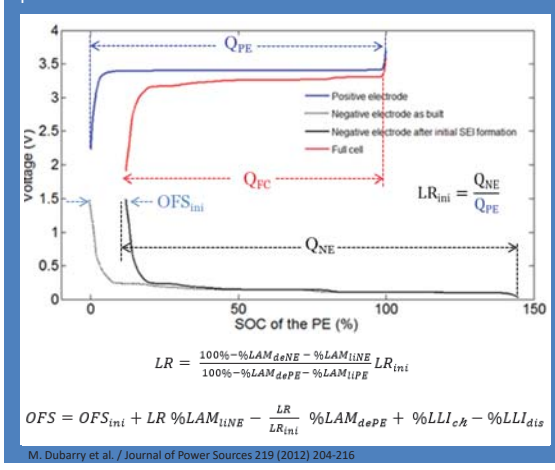
Methodology: use computer assisted voltage curve generation to adapt the estimator response to the degradation path without a large matrix of experiments or intensive calculations.



All possible thermodynamic cell degradation

Cell degradation emulation via computer assisted voltage curve generation

Full cell voltage calculated from half-cell data and two parameters: LR & OFS



$$LR = \frac{100\% - \%LAM_{deNE} - \%LAM_{liNE}}{100\% - \%LAM_{dePE} - \%LAM_{liPE}} LR_{ini}$$

$$OFS = OFS_{ini} + LR\ \%LAM_{liNE} - \frac{LR}{LR_{ini}}\ \%LAM_{dePE} + \%LLI_{ch} - \%LLI_{dis}$$

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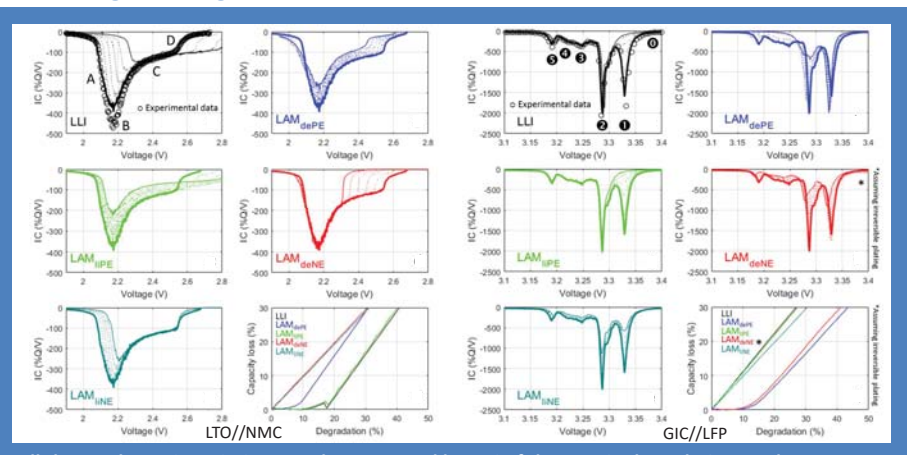
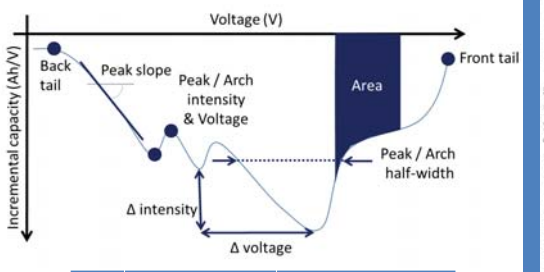


All thermodynamic variations can be expressed by a % of the 3 main degradation modes: loss of Li inventory (LLI), loss of active material at the positive (LAM_{PE}) and negative (LAM_{NE}).

Principles

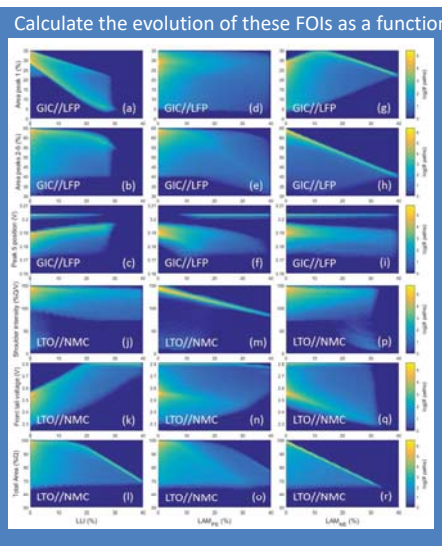
To decrease of the database size (> 100 GB for 1% accuracy on all 3 modes), **features of interest (FOI)** on the voltage curves (V vs. Q, IC, DV…) can be used.

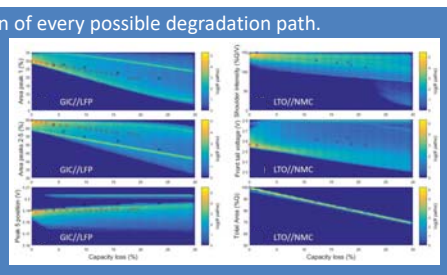
Possible FOIs:



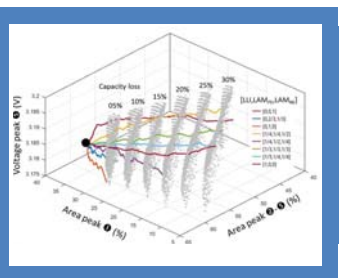
	GIC///LFP cell	LTO//NMC cell
FOI1	Area of peak ❶	Intensity of feature C
FOI2	Area of peaks ❷-❺	Voltage of feature D
FOI3	Position of peak ❺	Overall area
FOI4	Area of peak ❼	N/A

Calculate the evolution of these FOIs as a function of every possible degradation path.

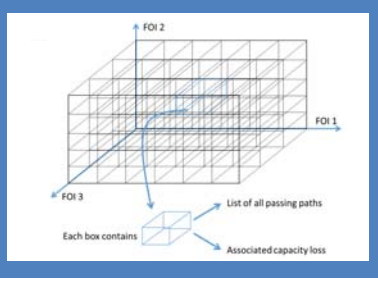




However, the **COMBINED** evolution of the FOIs in a multidimensional space is **more effective in quantifying** capacity loss and degradation.



- **No FOI alone is a sufficient proxy for capacity loss nor degradation modes quantification**.
- **<u>It highlights that a complete sensitivity analysis is necessary before selecting any FOI for diagnosis/prognosis purposes.</u>**



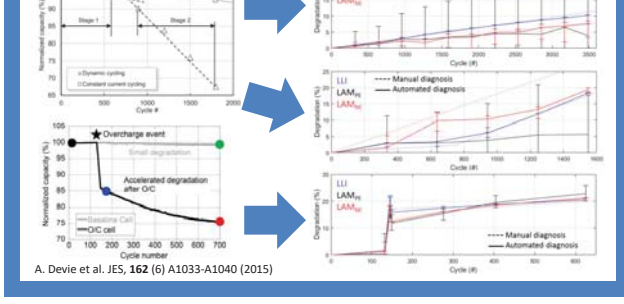
n-D look up table can be deciphered and embedded in BMS

Block size depends on resolution of the experimental data and the spread of the simulated FOIs values

Validation

Experimental: 3 test cases taken from previous studies

1. GIC//LFP: **Good agreement for LLI and LAM_{NE}. LAM_{PE} inaccuracy was expected.**
2. GIC//LFP (dynamically aged): decent agreement for LLI and LAM_{NE}, but V resolution was too low (10 mV) to accurately use with FOI3.
3. LTO//NMC (overcharge event): **Excellent agreement for all 3 modes.**



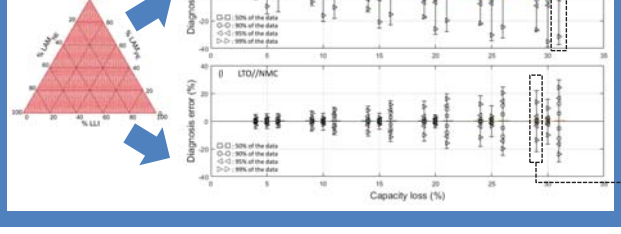
Modeling: 5000 different degradation paths

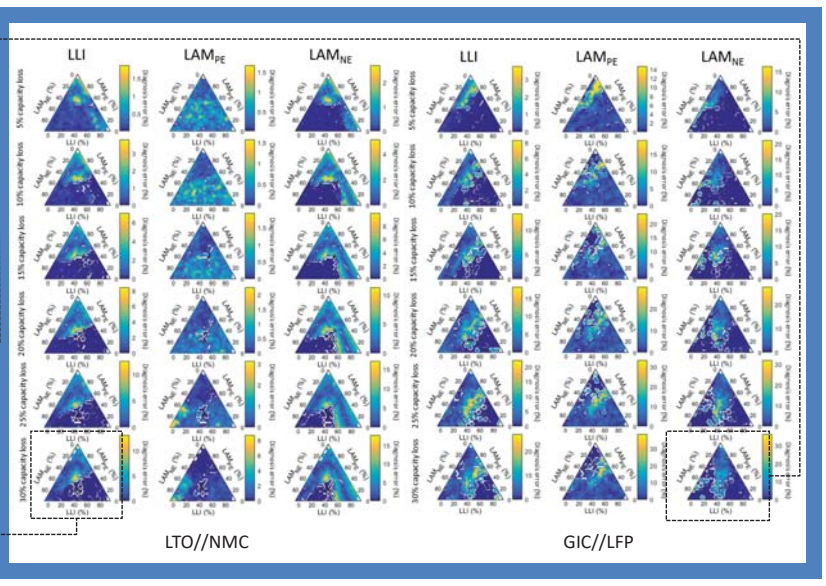
- To verify universality, more test cases need to be investigated.
- Lookup table tested versus initial 5000 paths database at different ages.

GIC//LFP: 1.3% $error_{average}$, $error_{max} \leq 5\%$ for ~ 90% of the dataset

LTO//NMC: 0.1% $error_{average}$, $error_{max} \leq 1\%$ for ~ 90% of the dataset (except for LAM_{NE}: 12%)

- Error distribution can be visualized on ternary plots: hot spots.





Conclusions & Perspective

- ✓ The new approach proposed in this work is a **multi-step method** where **only the final multidimensional look-up table is to be embedded** to enable a low computing but robust diagnosis of the battery degradation.
- ✓ Originality resides in the **consideration of the variations of all FOIs concurrently by using detection in an n-D space for n FOIs.** This enables having accurate prediction even **when each FOI taken separately cannot provide a conclusive diagnosis**.
- ✓ Although promising, the method **does have some limitations**: The first steps are computation-intensive, chemistries with large voltage plateaus might be tricky to diagnose, and some FOIs could disappear with aging and hamper the diagnosis.
- ✓ Nonetheless, our study presents a method which was very light on calculation at the BMS level and was, theoretically, accurate for 90% of all the possible degradation paths for commercial GIC//LFP and LTO//NMC cells.

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