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Research Alliance

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MODELLING OF LI-ION BATTERIES DYNAMICS USING IMPEDANCE SPECTROSCOPY AND PULSE FITTING: EVS APPLICATION

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Technology Research Centre

- Multidisciplinary Applied Research & Product Development (250 people, 20.2M€ income)
- Specialists in power electronics, energy storage and control

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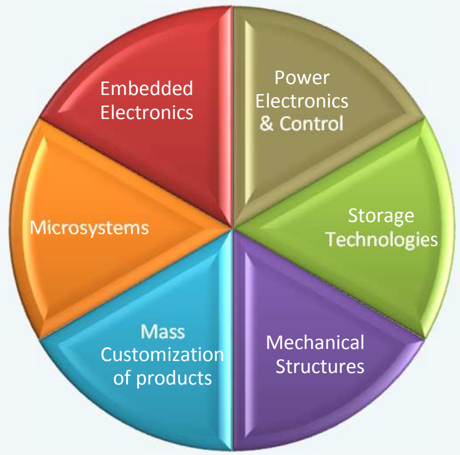
Specialized in Multi-Technology Integration



Component → Cell → Module → Battery Pack → Integration → End user

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Battery Management

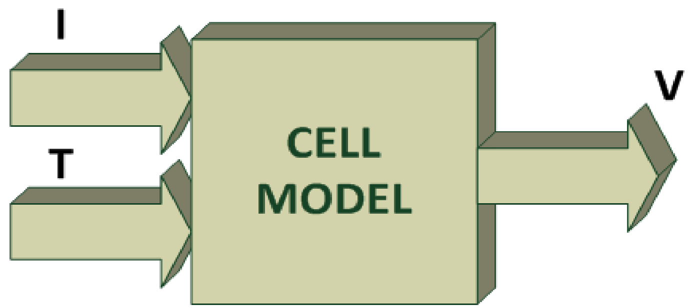
- In Li-ion batteries a BMS is required
- Battery state diagnosis is a key point (SOC, SOH)

EVs

- An accurate SOC determination is critical
- Specially challenging in HEVs
- A wide variety of dynamics must be modelled according to accelerations and decelerations

State diagnosis algorithms

- Advanced techniques for accurate estimation
- Necessity of a battery model



Targets

- Low voltage error
- Valid in all SOC and temperatures

Objectives

- Compare the main characterization techniques for obtaining a cell model.
- Propose a cell model suitable to be used in state estimation algorithms.
- Validate the performance of the model using experimental tests with real profiles.

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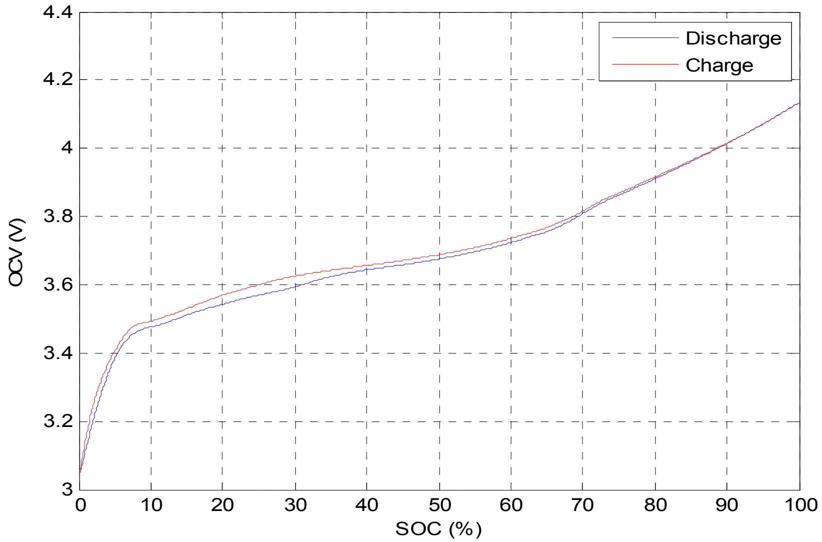
1. Introduction
2. Characterization of the cell model
3. Experimental validation
4. Conclusions

Characterization of the cell model

Statics sub-model

- OCV-SOC relationship
- Use of look-up tables
- Requires:
  - Hysteresis modelling
  - Dependence with temperature

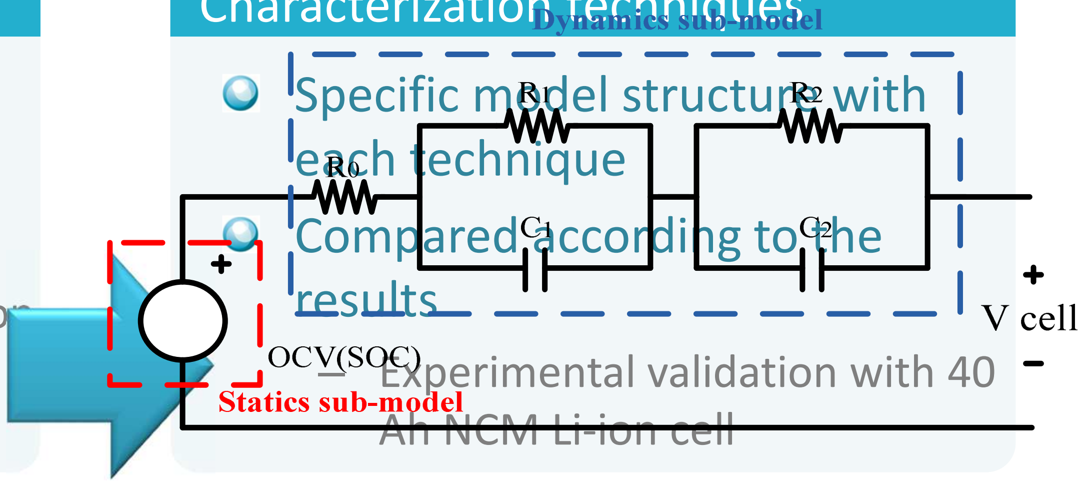


Dynamics sub-model

- Which model must be used?
- How characterize it?
  - Time domain identification
  - Frequency domain identification

Characterization techniques

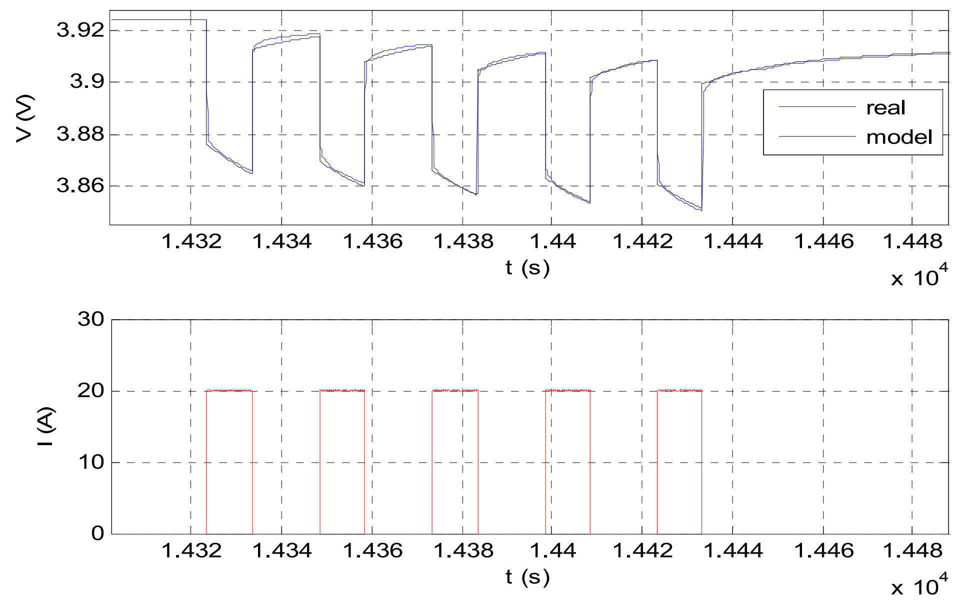
- Specific model structure with each technique
- Compared according to the results
  - Experimental validation with 40 Ah NCM Li-ion cell



Characterization of the cell model

Time domain characterization

- Second order Randles model
- Parameters fitted according to the time response of the cell
- Use of least squares technique
- 20 A, 10 s discharge pulses at 25ºC
- Test required at different SOCs

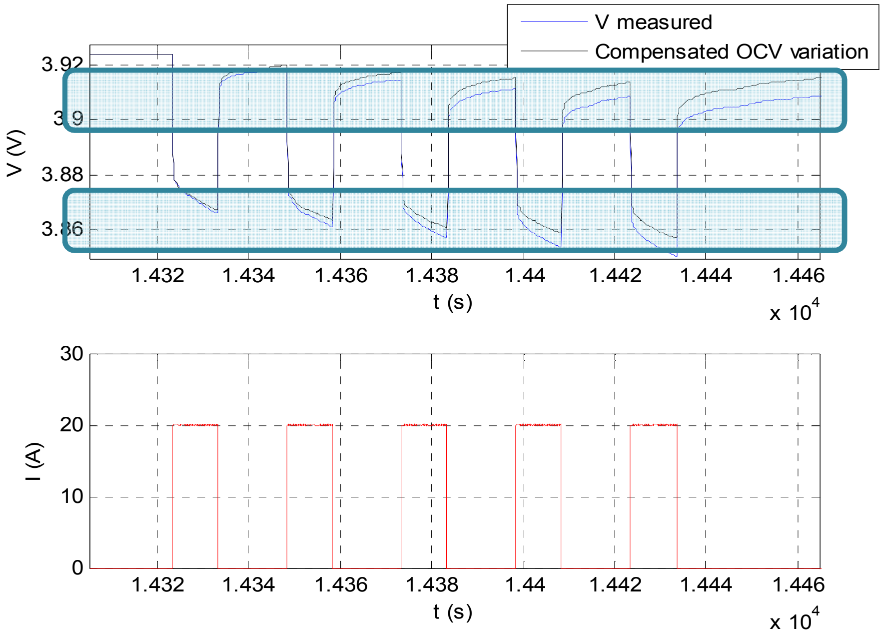


$$V_{cell}(k+1) = OCV\big(SOC(k+1)\big) - R_0\, I(k+1) - [V_{RC1}(k)\, e^{-\frac{T_s}{R_1 C_1}} + R_1\, I(k)(1 - e^{-\frac{T_s}{R_1 C_1}})] - [V_{RC2}(k)\, e^{-\frac{T_s}{R_2 C_2}} + R_2\, I(k)(1 - e^{-\frac{T_s}{R_2 C_2}})]$$

Characterization of the cell model

Relevant considerations

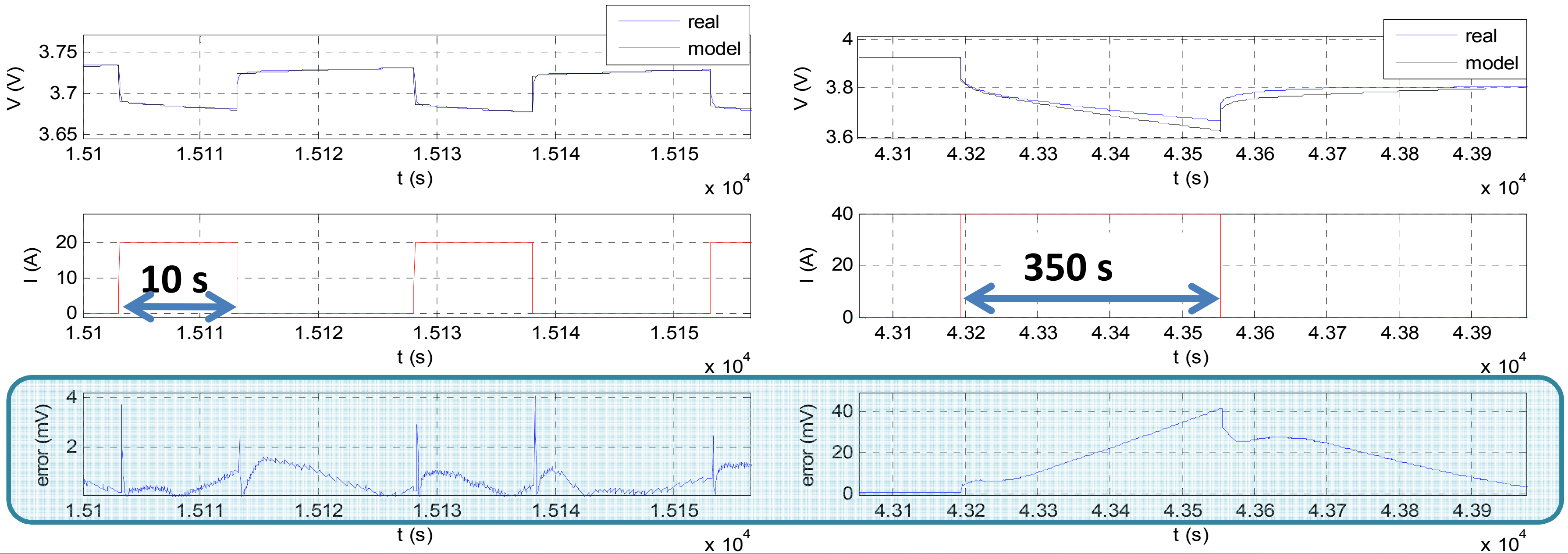
- The compensation of the OCV variation due to the small changes in the SOC during the tests is essential (0.8% SOC-> 4.7 mV)



Characterization of the cell model

Time domain characterization drawbacks

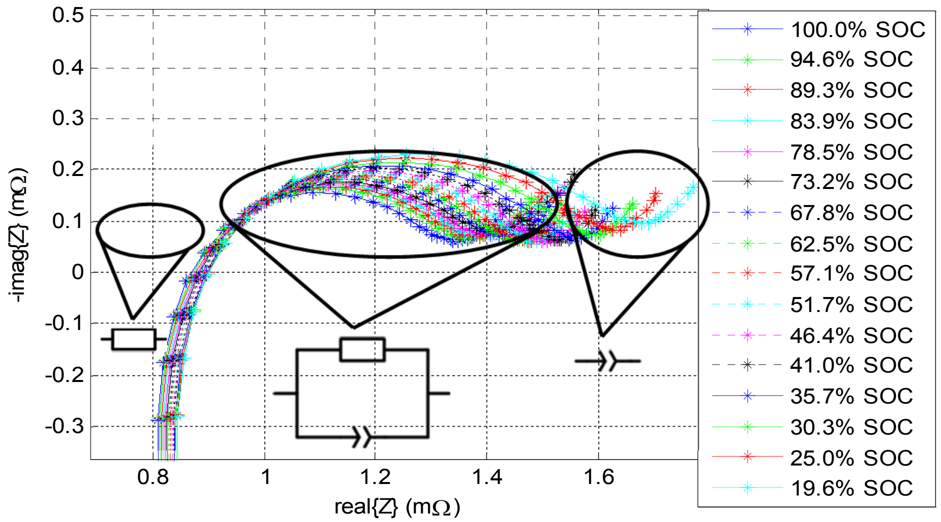
- Sensitive to initialization and changes in the length of the set of samples
- Dependence on the width of the used pulses in the characterization
- Variable parameters between different characterizations, making difficult the result comparison and the data interpolation

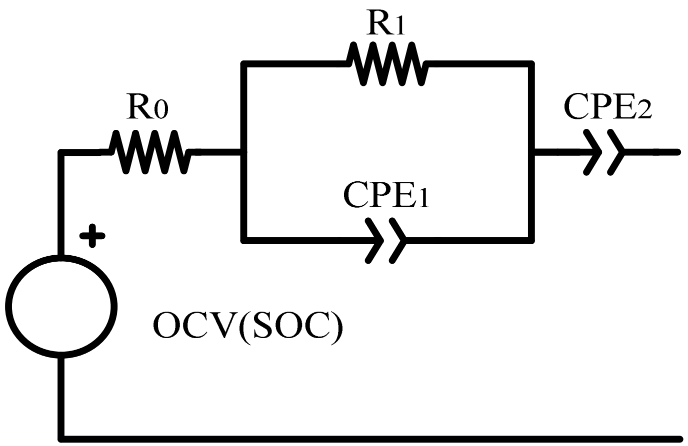


Characterization of the cell model

Frequency domain characterization

- Cell impedance measured at several frequencies
- Requires EIS in all SOC and temperature range
- Circuit elements adjusted to the measured impedance





$$Z_{CPE} = \frac{\sigma}{(j\omega)^{\alpha}}\,, \qquad 0 < \alpha < 1$$

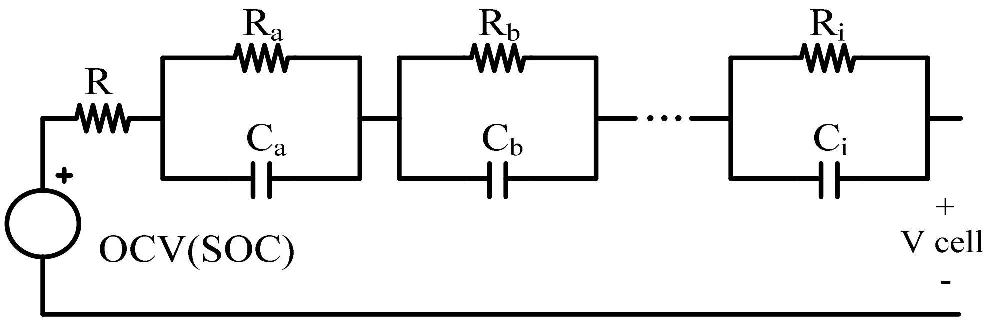
Characterization of the cell model

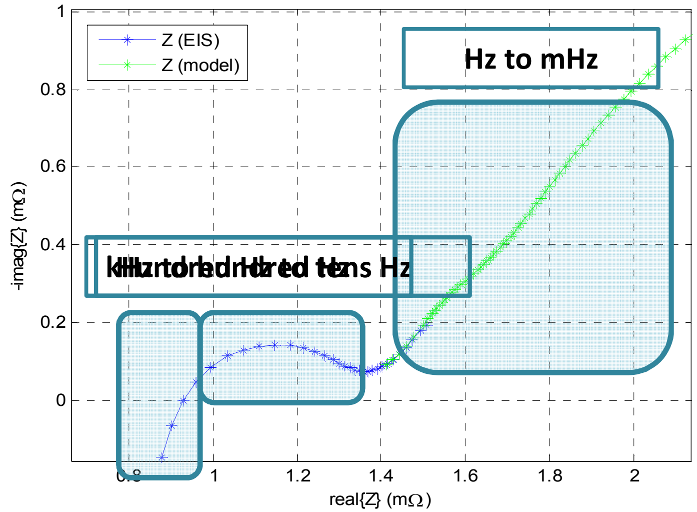
Frequency domain characterization

- The inductive behaviour at high frequencies is negligible
- The dynamics represented in the R_1//CPE_1 can be also neglected

$$Z = R + \frac{\sigma}{(j\omega)^{\alpha}} \qquad (R = R_0 + R_1)$$

- The CPE can be approximated using a Foster structure





Characterization of the cell model

Frequency domain characterization advantages

- Easy to obtain a high order model
- Accurate representing a wide range of dynamics
- Less variable parameters between different characterization tests
- Suitable for linear interpolation

Frequency domain characterization drawbacks

- Time and equipment required
- Reconnections of the cell to the EIS equipment can produce a variation in the impedance

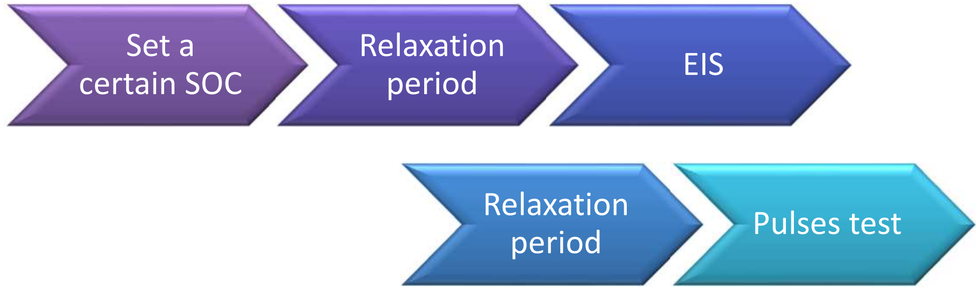
Characterization of the cell model

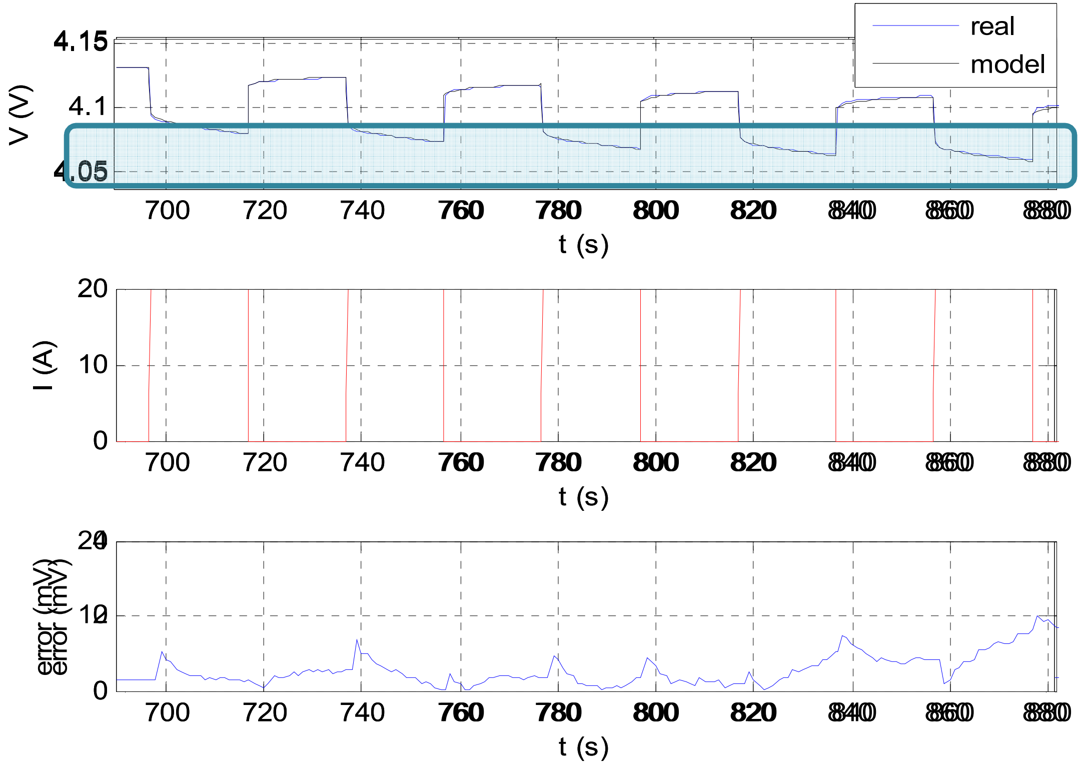
Proposed combined methodology

- Requires EIS and pulse tests
- Capable of modelling a wide range of frequencies
- Test repeated over all SOCs

Allows

- Validation in time domain
- Correction of the internal resistance value
- Simple to calculate the dependence of the internal resistance with current





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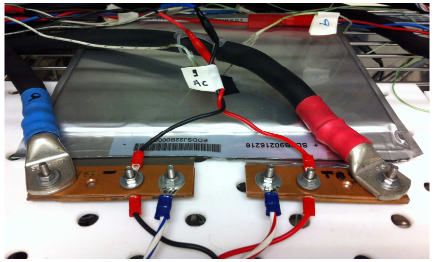
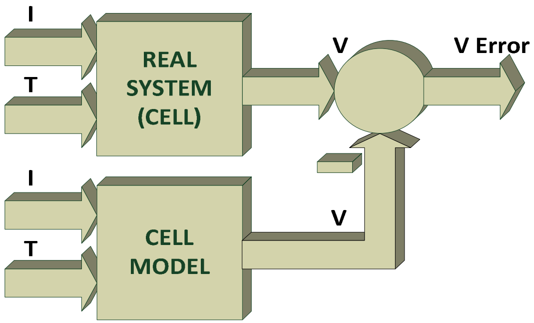
Experimental validation

Considerations

- Tests with a 40 Ah NCM Li-ion cell
- Results of the combined methodology
- Model can be directly used for an open loop SOC estimation
- Equivalent SOC error





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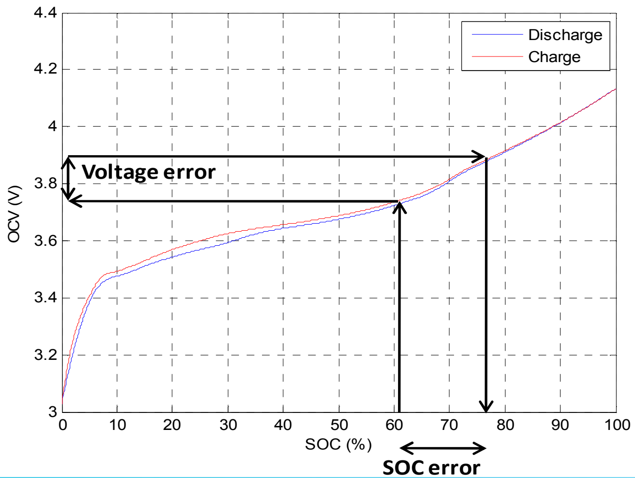
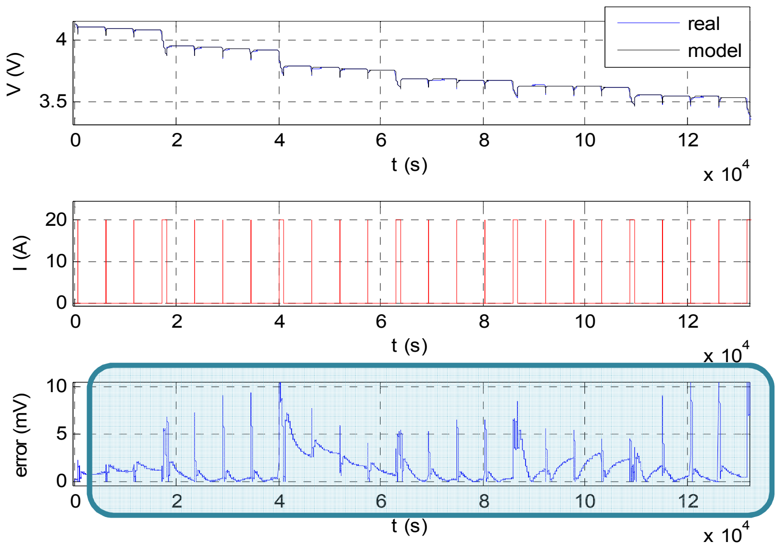
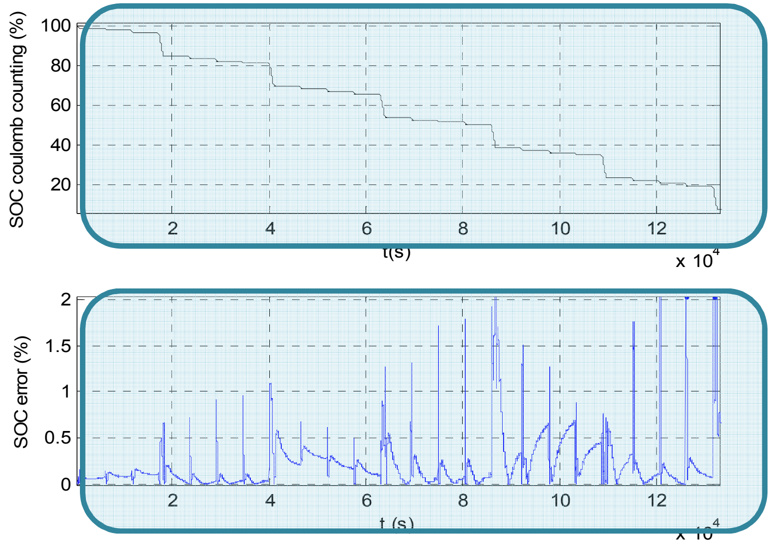


Experimental validation

C/2 Pulses from 10 s to 900 s all SOC

- 25 ºC
- Low voltage error
- Low equivalent SOC error





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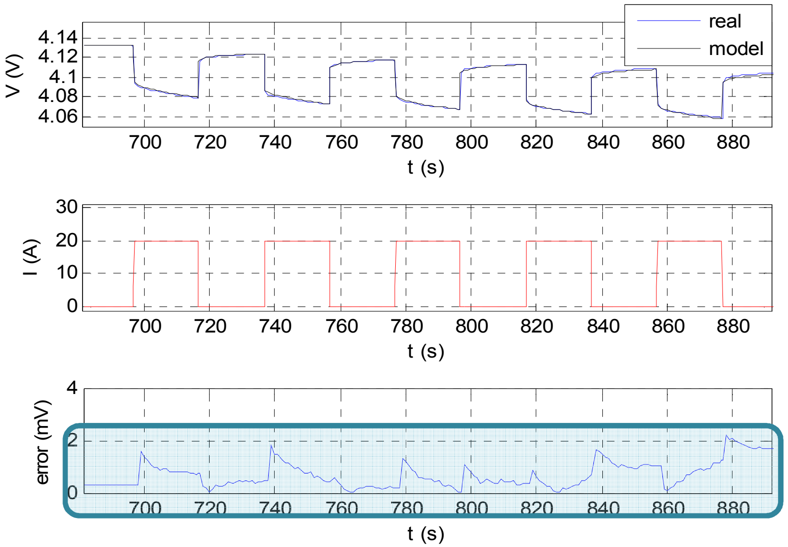

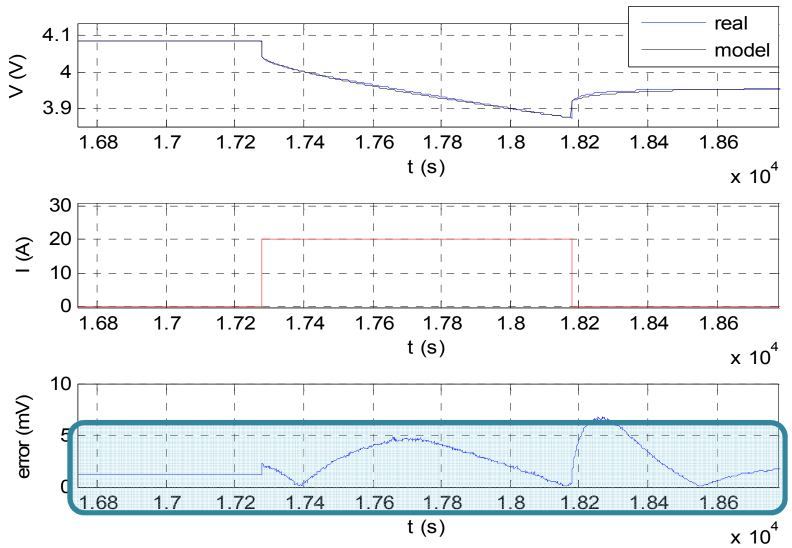

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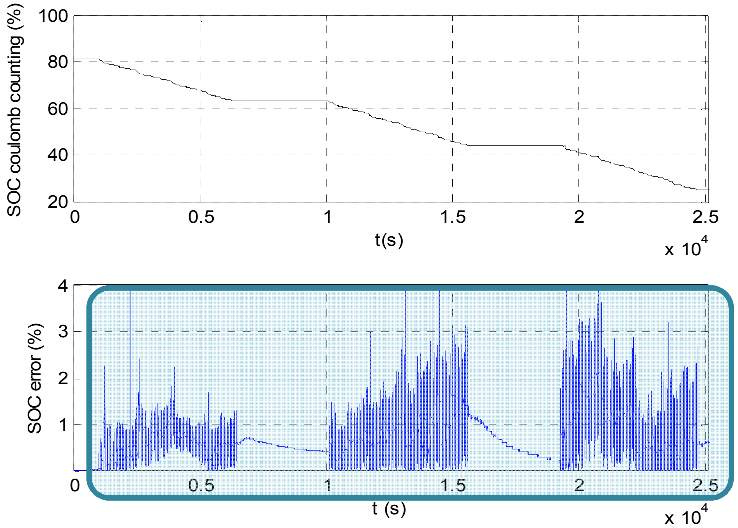
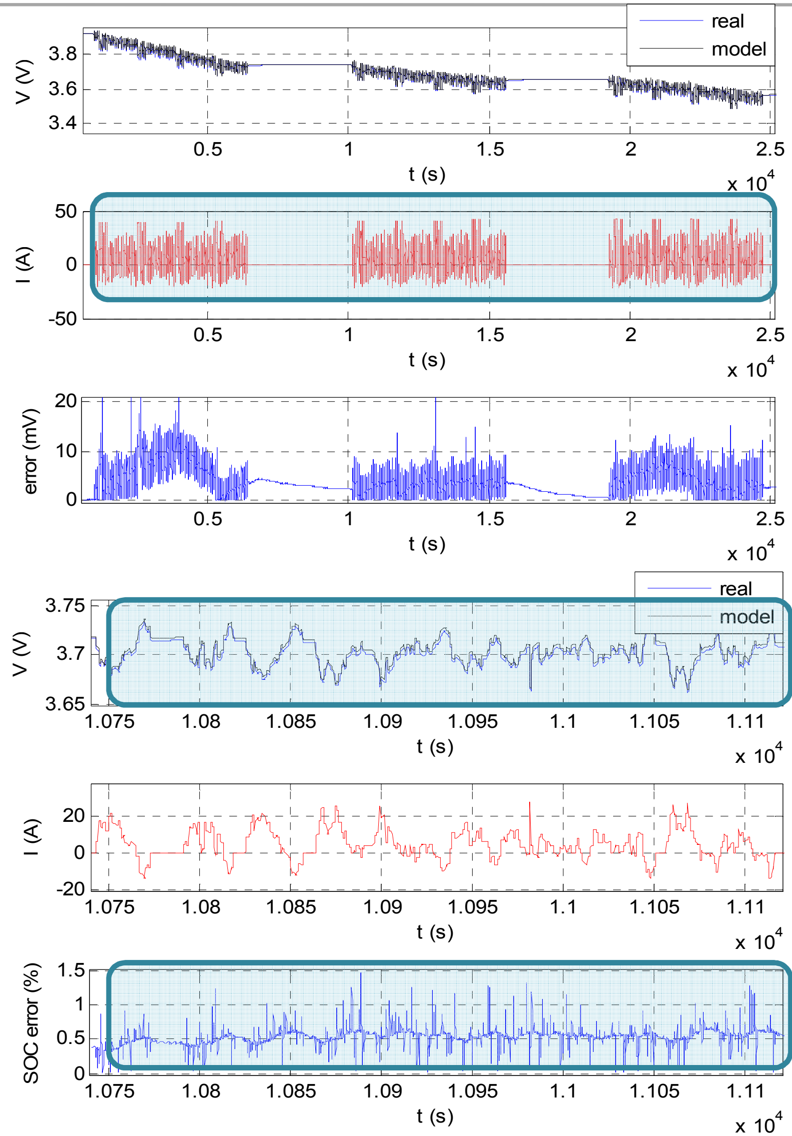
Experimental validation

FUDS cycles @ 25ºC

- less than 12 mV error
- Increasing offset error by hysteresis effect in OCV
- Low equivalent SOC error





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Conclusions and Future Lines

Conclusions

- 2 existing characterization methodologies analyzed and compared
- A combined methodology has been proposed
- Model validated in all SOC range and for different dynamics using pulses and FUDS driving cycles
- Suitable for a real time estimation in a BMS (Can be used in a closed loop algorithm like EKF)

Future lines

- Validate the model at varying temperature and with other cell chemistries (LiFePO4)
- Analyze the degradation effect in the model parameters
- Integrate the model in a closed loop estimator for SOC and SOH

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Muchas gracias

Thank you

Merci beaucoup

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Other Ikerlan Presentations

Dialogue session: Monday 2013-11-18, 13:00-15:00
THERMAL MANAGEMENT SYSTEMS' DESIGN METHODOLOGY FOR TRANSPORT APPLICATIONS
Nerea NIETO

Session 1B: Monday 2013-11-18, 15:15-16:35
MODELLING OF Li-ION BATTERIES DYNAMICS USING IMPEDANCE SPECTROSCOPY AND PULSE FITTING: EVS APPLICATION
Unai VISCARRET

Session 2B: Monday 2013-11-18, 16:50-18:10
VALIDATION OF THE METHODOLOGY FOR LITHIUM-ION BATTERIES LIFETIME PROGNOSIS
Elixabet SARASKETA ZABALA

Session 7B: Wednesday 2013-11-20, 09:00-10:20
PROPOSAL AND VALIDATION OF A SOC ESTIMATION ALGORITHM OF $LiFePO_4$ BATTERY PACKS FOR TRACTION APPLICATIONS
Maitane GARMENDIA