Lithium-ion battery model and experimental validation

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ABSTRACT

A simple battery model is useful for:

- Sizing of the storage system for a particular application.
- Designing other elements connected to the battery.
- Managing the storage system operation.

This poster consists on:

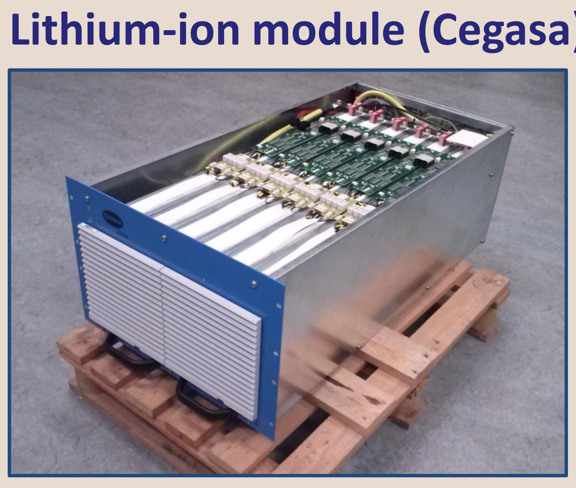
- Tests to characterize a lithium-ion battery at T_a=23 ºC.
- Methodology to fit the parameters of the battery model.
- Parameter trends related to the State of Charge.
- Experimental validation and model accuracy.

EXPERIMENTAL SET-UP

Battery

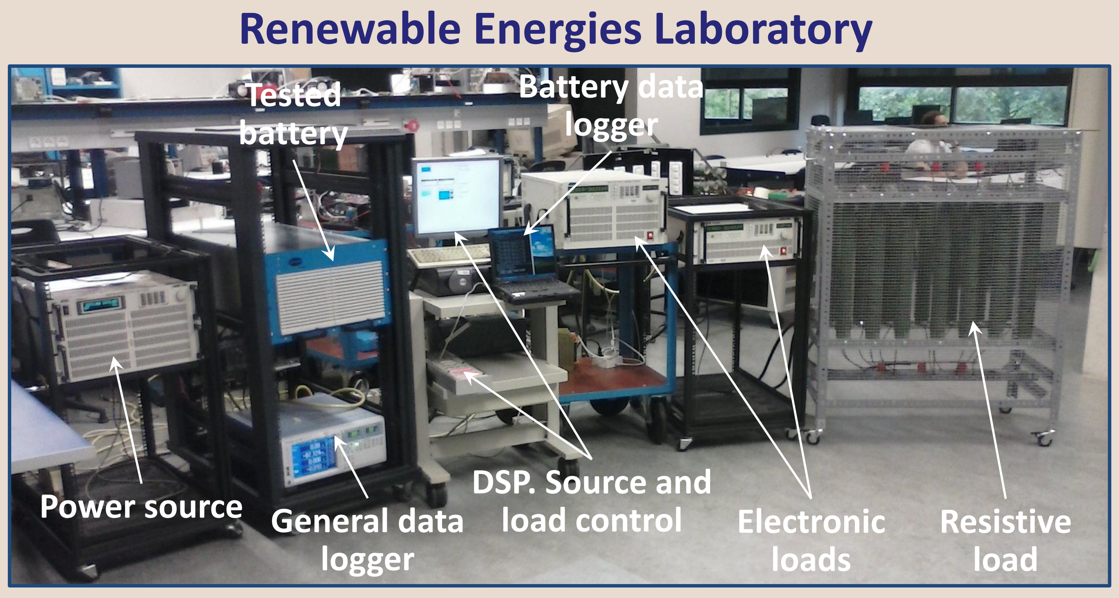
Lithium-ion module (Cegasa)

- 36 series-connected pouch cells.
- Anode: Carbon black.
- Cathode: $Li(Ni_{1/3}Mn_{1/3}Co_{1/3})O_2$.
- Electrolyte: Organic polymer.
- C = 40 Ah.
- 104 V≤ v ≤ 149 V.
- $i_{max,ch}$ = 80 A; $i_{max,disch}$ = 200 A.

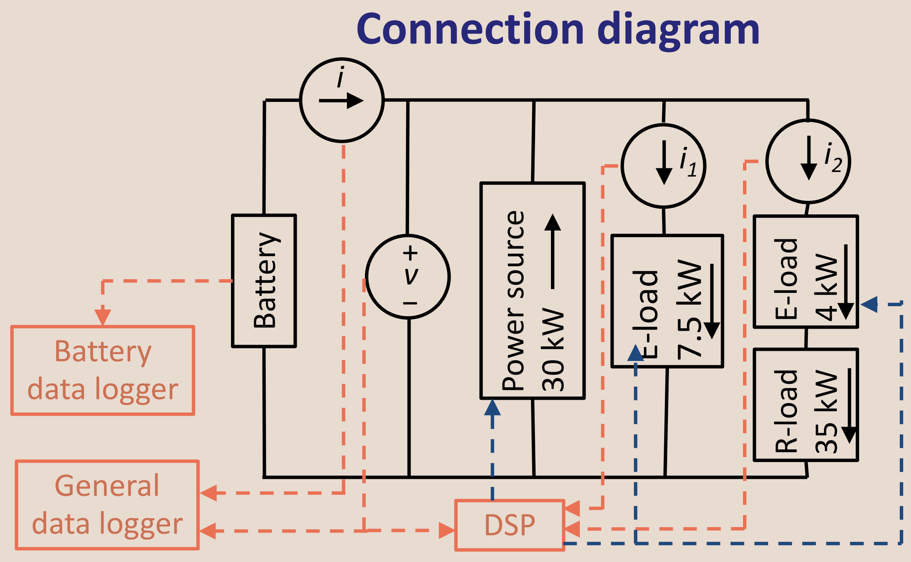


Test bench

Renewable Energies Laboratory

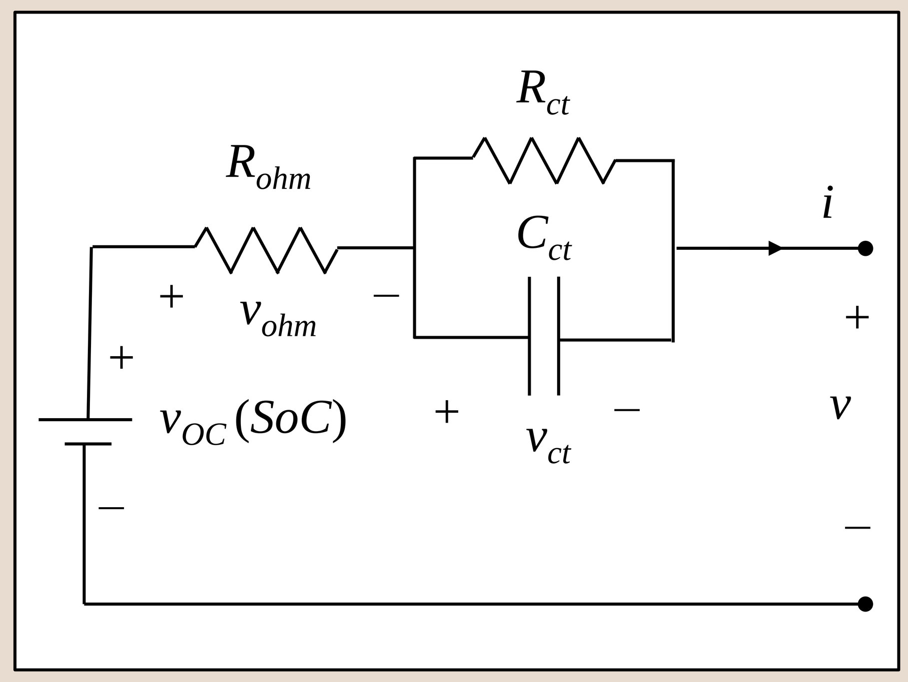


Connection diagram



MODEL

Circuit diagram



State of charge

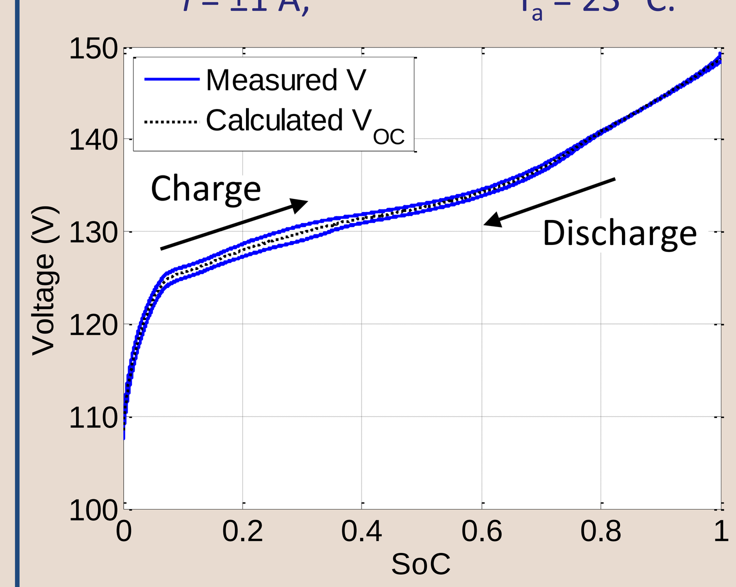
$$SoC = \frac{1}{C_N}\int i(t)dt$$

Open-circuit voltage

$$v_{OC}(SoC) = \sum_{j=0}^{8} a_j \cdot SoC^j$$

Open-circuit test

i = ±1 A, T_a = 23 ºC.



NMC cathode → No hysteresis loop.

Least squares fit

Coefficient	Value
a_0	110
a_1	384
a_2	−3785
a_3	19976
a_4	−59274
a_5	1024800
a_6	−102331
a_7	54734
a_8	−12147

Impedance

Experiment details

- 40 A charge and discharge current steps.
- Different *SoC* levels.
- T_a=23 ºC.
- Voltage measurement.
- Mathematical fit to each experiment.

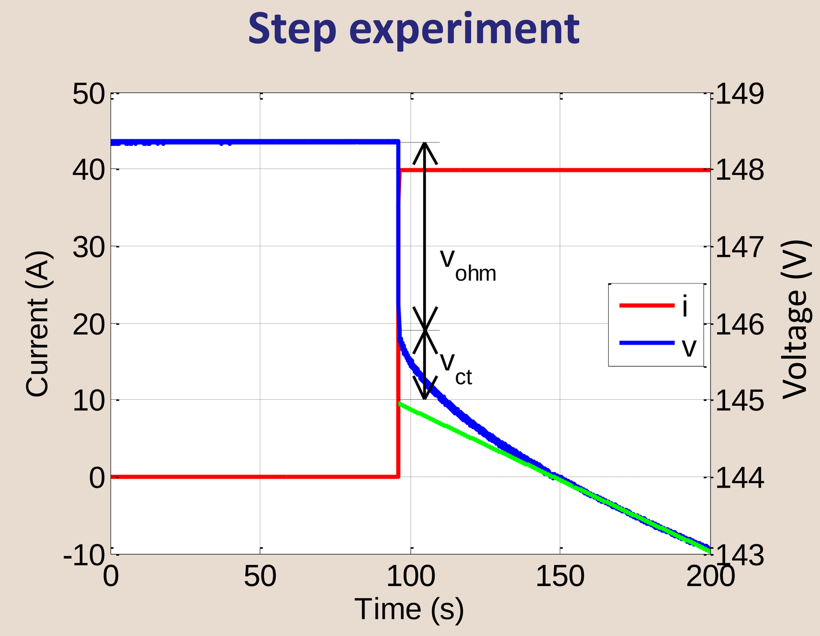
Fitting equation

$$v_{ohm} = i \cdot R_{ohm} \qquad v_{ct} = i \cdot R_{ct} - R_{ct} \cdot C_{ct}\frac{dv_{ct}}{dt}$$

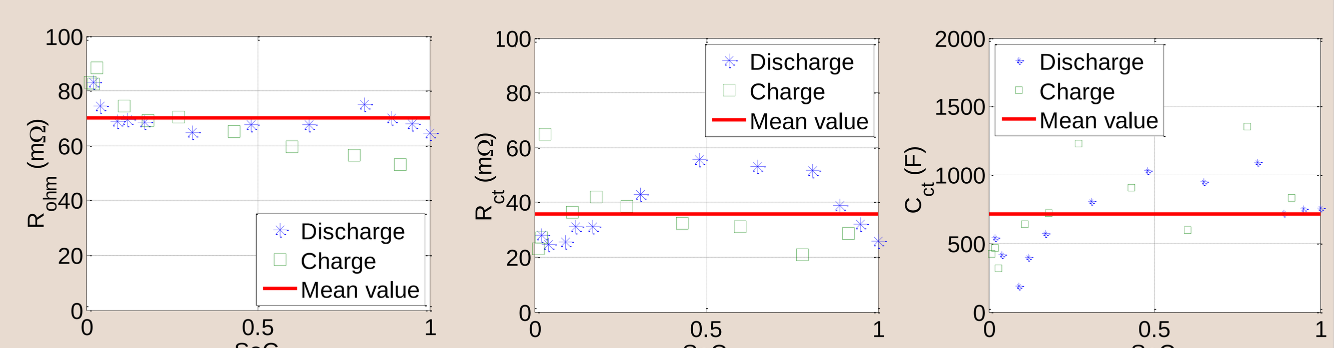
Given that $v_{ct} = v_{OC} - v_{ohm} - v$ and $\frac{dv_{ohm}}{dt} = 0$ for constant i:

$$v = v_{OC} - i \cdot (R_{ohm} + R_{ct}) + R_{ct} \cdot C_{ct}\left(\frac{dv_{oc}}{dt} - \frac{dv}{dt}\right)$$

Step experiment



Least Squares fit to each step experiment



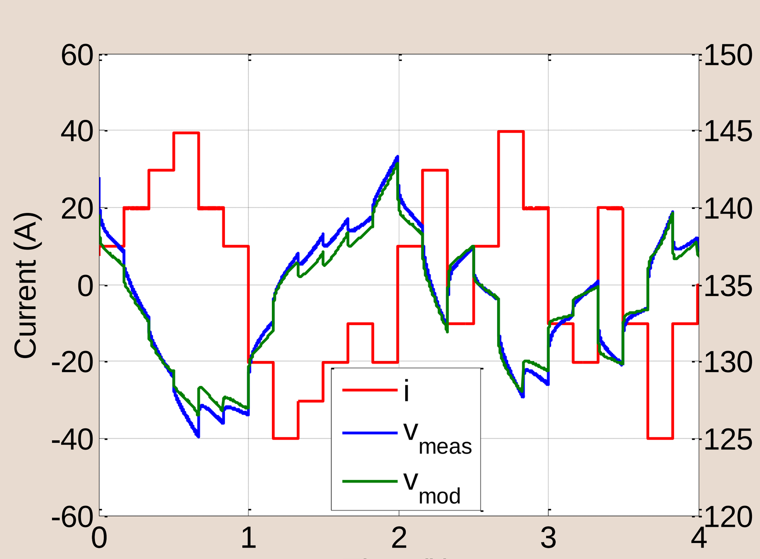
- Similar behaviour in charge and discharge.
- No clear dependency on the *SoC* is observed.

Global fit

$$R_{ohm} = 70.2m\Omega \qquad R_{ct} = 35.7m\Omega \qquad C_{ct} = 714.6F$$

EXPERIMENTAL VALIDATION

4-hour stepped current



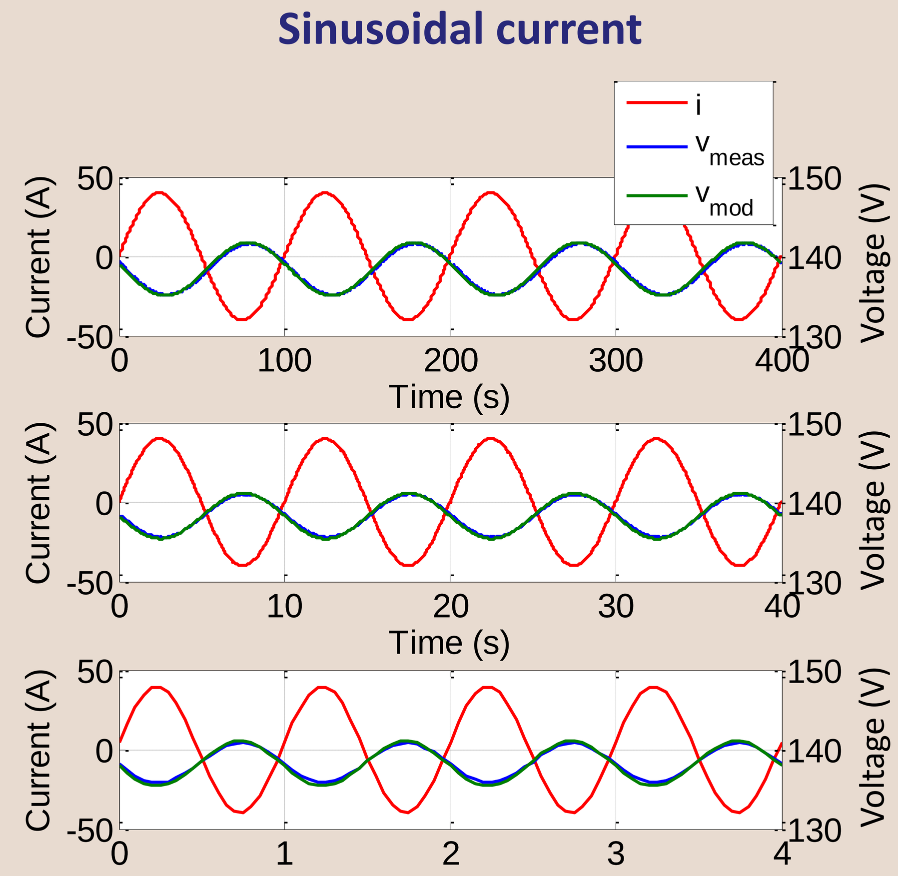
Root-Mean-Square Error

$$RMSE = \frac{1}{n}\cdot\sum_{j=1}^{n}\left(v_{mod,j} - v_{meas,j}\right)^2$$

$$RMSE = 0.747V$$

- Excellent dynamic performance.
- Negligible cumulative error.
- Constant error for intermediate voltage.

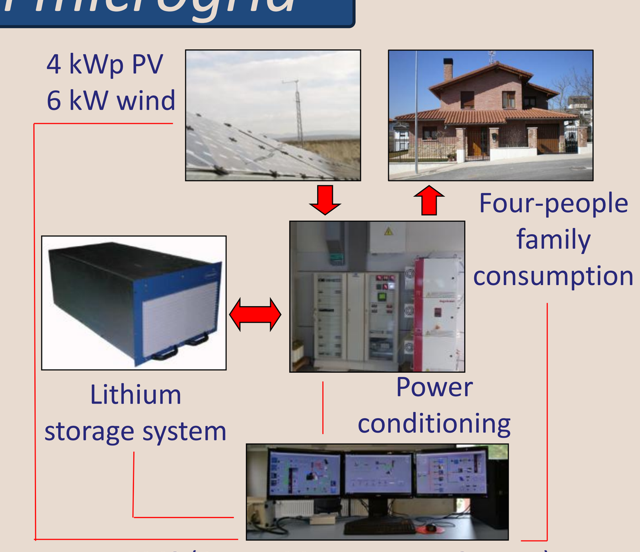
Sinusoidal current



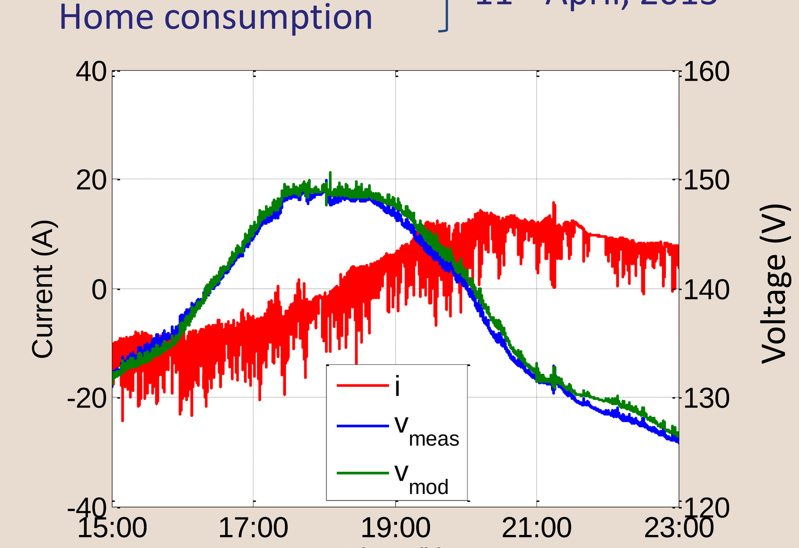
f (Hz)	0.01	0.1	1
RMSE (V)	0.2	0.17	0.25

- Good performance for a wide frequency range.
- Frequency-independent accuracy.

Real microgrid



Renewable generation
Home consumption } 11th April, 2013



$$RMSE = 0.533V$$

CONCLUSSIONS

- ✓ 133 V, 40 Ah commercial battery pack analysed.
- ✓ Simple model with accurate results for dynamic response and open-circuit voltage prediction.
- ✓ Applicable model and methodology to other types of lithium-ion batteries.
- ✓ Further experimental work is required for ambient temperature different from 23 ºC.
- ✓ The model is validated with stepped and sinusoidal current experiments.
- ✓ Good performance in a real, domestic microgrid with renewable energy generation.

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