HYBRIS

Enhanced Hybrid Storage Systems

Battery Modelling Principles & Advanced Battery Management System

Workshop on energy storage and its crucial role in the energy transition with focus on hybrid solutions

Presented by Tom Dollfus – Project Manager Storage System at CEA

- 1st HYBRIS Workshop
- Horcynus Orca Foundation, 23rd June 2022

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Agenda

- ❑ **Battery modelling principles**
  - ❑ Modelling purpose (*Why do we need to model batteries?)*
  - ❑ Various approaches (*What types of models are existing?)*
  - ❑ Battery cell model structure (*What is made of a semi-empiricial battery model?)*
  - ❑ Hybris implementation

- ❑ **Advanced Battery Management System (ABMS)**
  - ❑ ABMS purpose
  - ❑ Hybris implementation

- ❑ **Perspectives**

Battery modelling principles

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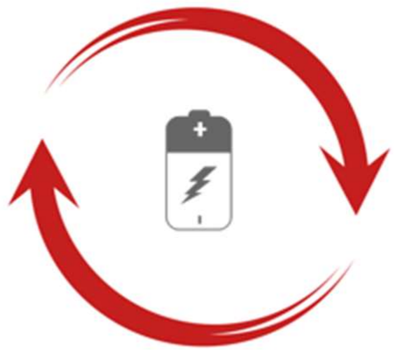
- **Battery modelling purpose**

Battery life

- **Sizing** of the battery system for field applications (stationary systems)
  
  - Grid tied : grid services (frequency support, energy shifting, peak shaving…)
  - Micro grid: islanding operation / self-consumption maximization..
- **Diagnosis** during system operations
  
  - Enhance BMS features: state of health, state of charge, resistance,…
- **Follow Up & Prognostic**
  - Check up tests for specific field applications
  - Life assessment
- **Control strategies**
  - System management optimization
- **Second life** application: new battery application



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Battery modelling principles

- **Various modelling approaches**

○ Electrochemical models

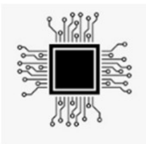
Model all or part of inherent cell's electrochemical reactions based on cell's physico-chemical characteristics; requires intensive physical material data collection.

○ Empirical models

Model the evolution of cell's behavior based on mapping identification methodology; requires numerous cell's tests results.

○ Semi-empirical model

Model physical & chemical phenomena occurring in the cell by electrical equivalence. This approach allows the coupling of an aging model and behavioral model. The parameters' evolutions of this Equivalent Circuit Model are usually identified using experiments;



○ Numerical/mathematical models

This approach uses accessible physical measures (Voltage, Current or Temperature) of the cell. Based of a first learning phase on a maximum of monitoring data followed by a verification phase of model's prediction on additional data.

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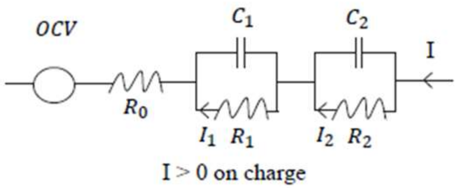
Battery modelling principles

❑ Semi-empirical approach: Battery cell model structure

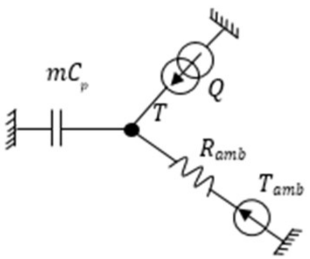
- Electrical model



$$\tau_1 = R_1 * C_1$$
$$\tau_2 = R_2 * C_2$$

Parameter	Unit	Description
OCV	V	Open Circuit Voltage
R0, R1, R2	Ω	Electrical resistance
τ_1, τ_2	s	Time constant for R//C
C_1, C_2	F	Capacities

- Thermal model



$$mC_p \frac{dT}{dt} = \dot{Q} - \frac{T - T_{amb}}{R_{amb}}$$
$$\dot{Q} = \dot{Q}_J + \dot{Q}_s$$

$\dot{Q}_J = R_0 I^2 + R_1 I_1^2 + R_2 I_2^2$: *Joule effect*

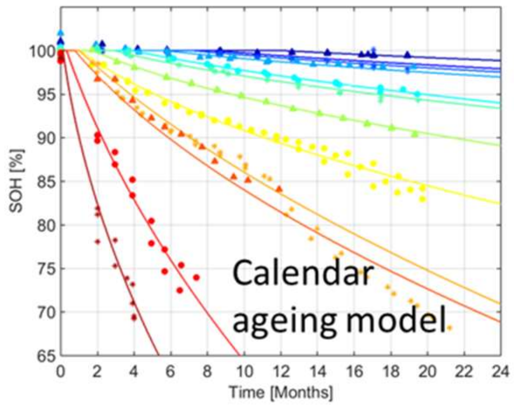
$\dot{Q}_s = IT\frac{\Delta S}{nF}$: *Entropic effect*

Parameter	Unit	Description
m	kg	Cell weight
C_p	$J.K^{-1}.kg^{-1}$	Specific calorific capacity
R_{amb}	$K.W^{-1}$	Thermal resistance between the cell and the near by environment
ΔS	$J.mol^{-1}.K^{-1}$	Entropy
F	$C.mol^{-1}$	Faraday constant
n	$s.u.$	Electron throughput

- Electro-thermal model : coupling electrical and thermal model

Battery modelling principles

- **Battery cell model structure**
  - Ageing model
    - Multiple degradation mechanisms: SEI growth, lithium plating, gas formation…
    - Ageing due to calendar & cycling



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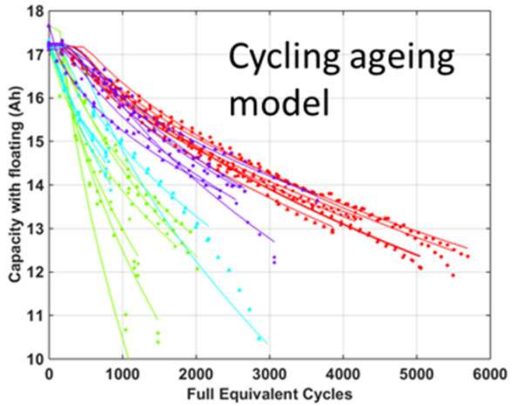
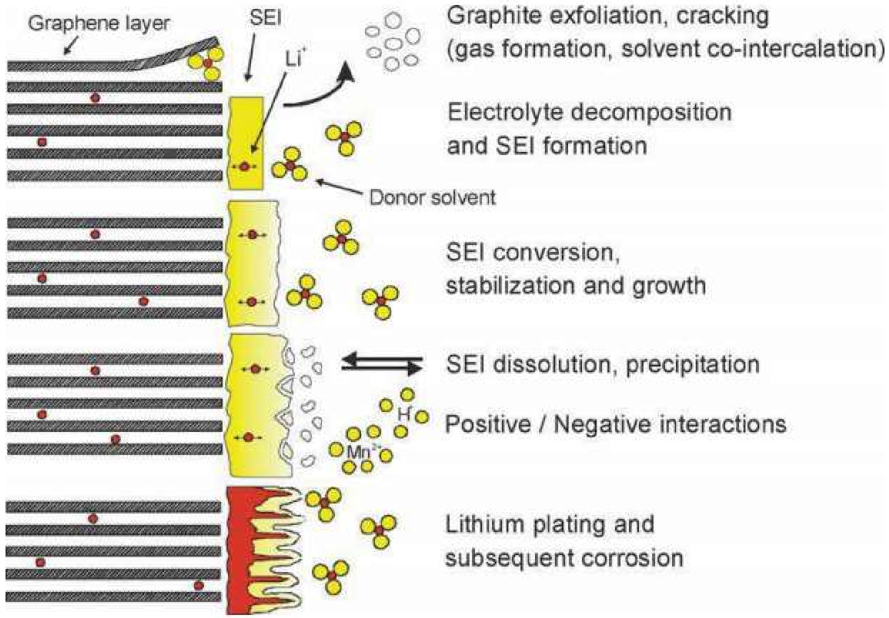




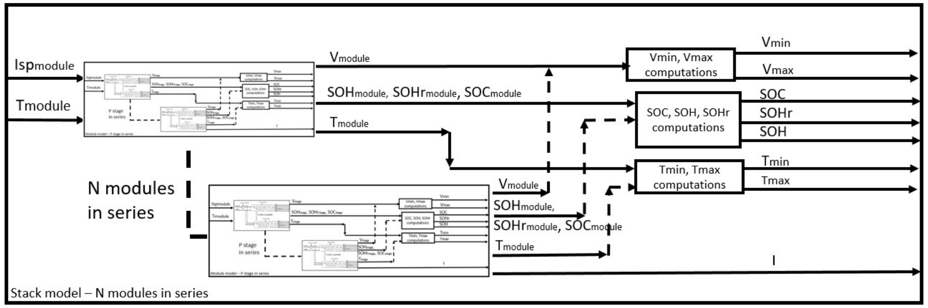
Ageing = Calendar degradation + Cycling degradation

$$\frac{dQ_{loss}}{dt} = \left(k_{cal}(T,SOC) + k_{cyc}(T,SOC,I,DOD) \right) . f_{deg}(Q_{loss})$$

Battery Modelling Principles

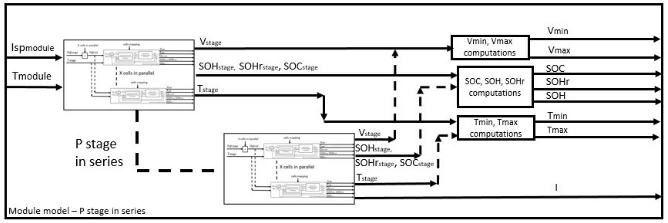
- From Cell to Stack model scale…

Stack model



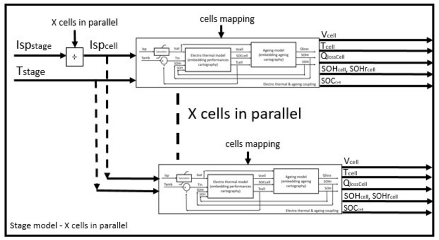
Series assembly of **module** model

Module scale



Series assembly of **stage** model

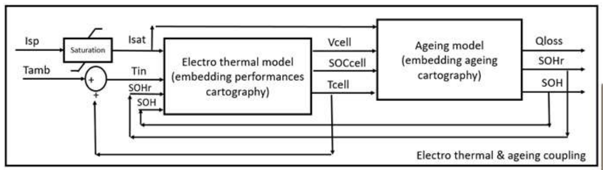
Stage scale



Parallel assembly of **cell** model

Scaling up methodology

Cell scale



Electro thermal & ageing model coupling

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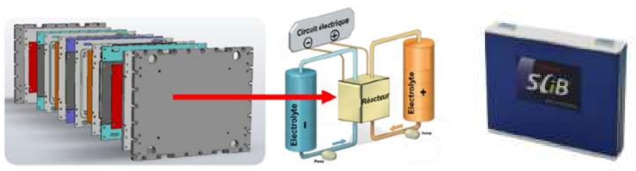
Battery Modelling Principles

- **HYBRIS implementation**

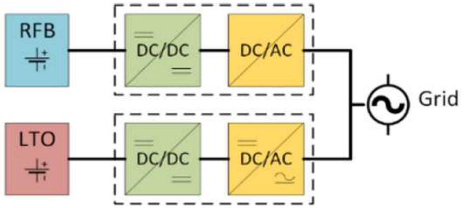
Technologies



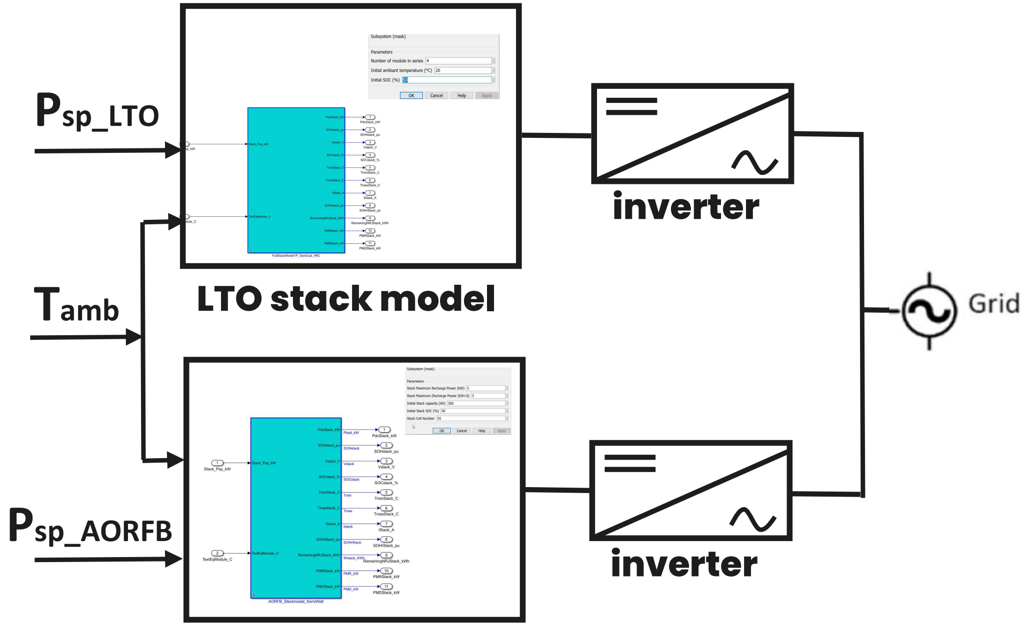
Aqueous Organic Red Flow Battery (AORFB)

Lithium Titanate Battery (LTO)

Demonstrator Electrical architecture



HYBRIS HESS MODEL



LTO stack model

AORFB stack model

AORFB & LTO model: HYBRIS main achievements

- ✓ Protected model supplied
- ✓ Common IO for both technologies
- ✓ Embedding Hybris Stack architecture with customizable parameters
- ✓ Embedding Hybris battery reference characteristics (cartographies)
- ✓ Model calibration based on manufacturers test data and datasheets (TOS & KEMI)

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Advanced Battery Management System

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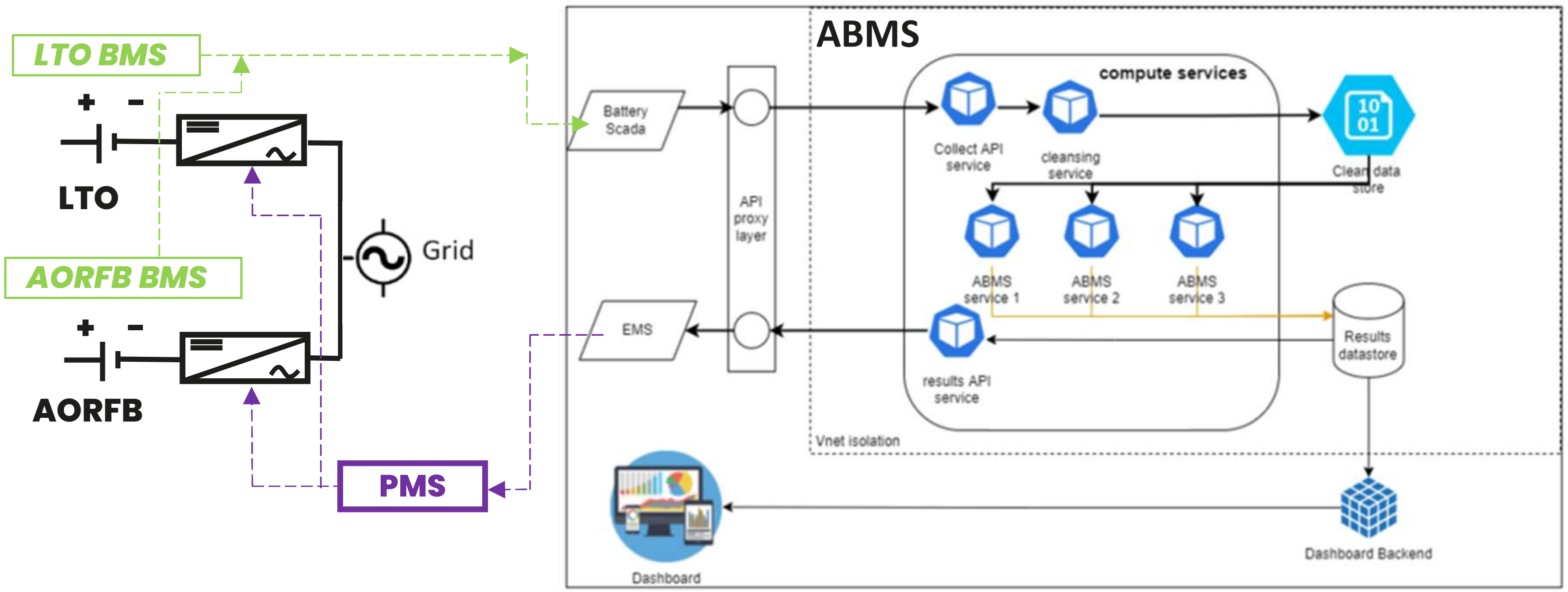
- **ABMS purpose**
  - Software As A Service (SAAS) solution to diagnose and predict the battery system conditions & lifetime
  - Embeds advanced features self-calibrated on operation data; aiming to enhance the Energy Management System (EMS) control and follow day to day operations
  - Assess BMS KPIs accuracy and provide additional relevant KPIs
- **Hybris demonstrator implementation**
  - IT control architecture principles



Site based | Cloud based

ABMS services

- ✓ EMS mapping updates (Pmax(SOC,T); ΔT(T,P); η(SOC,T,P))
- ✓ EMS battery index preference
- ✓ Diagnostic services (SOC & SOH verification, availability computation,…)
- ✓ Prognostic services (short term / long term battery KPIs & lifetime assessment)

BMS = Battery management System
PMS = Power management system (real-time control)
EMS = Energy management system (optimized control)

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Battery modelling
& Advanced BMS perspectives

Battery modelling future

- Expanding due to numerous and various application using battery storage
- Empirical methodology historically used but new methodologies start to show added values (physics, numerical,…)
- Targets
  - Reduction of battery testing (expensive & time consuming)
  - Improve modeling accuracy & be able to predict sudden death

Advanced BMS

- New solution offering new opportunities
  - Challenge BMS indicators
  - Capitalize on battery operation: update of embedded battery models based on operation data
- Targets
  - Support definition of optimal management strategies
  - Solution flexibility (multi-technology) and robustness
  - Plug & play solution

THANK YOU
FOR YOUR ATTENTION

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