5th International Hybrid Power Systems Workshop

Hydro power plant hybridization with battery energy storage system for primary frequency control

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PRESENTATION OVERVIEW

1. XFLEX HYDRO project and Vogelgrun demonstrator presentation
2. BESS sizing methodology
3. Battery ageing model and simulation results
4. Conclusion

XFLEX HYDRO PROJECT OVERVIEW

XFLEX HYDRO

- **EU project of 18 million €**
- **19 partners**

ALPIQ, ANDRITZ, ARMINES, cea, EPFL, MINES ParisTech, PSL, EDF, edp, NEW, Hes·so, INESCTEC, iha, POWER VISION ENGINEERING, GE, SuperGrid Institute, Universität Stuttgart, UPC, VOITH, zabala

- **7 demonstrators**
- **New hydropower technologies:**
  - Smart controls
  - Variable/fixed speed turbine systems
  - Battery-turbine hybrid

XFLEX HYDRO demonstrations:

A. Z'Mutt (Switzerland)

B. Frades 2 (Portugal)

C. Grand Maison (France)

D. Alqueva (Portugal)

E. Alto Lindoso (Portugal)

F. Caniçada (Portugal)

G. Vogelgrun (France)

VOGELGRUN DEMONSTRATOR

Objectives:

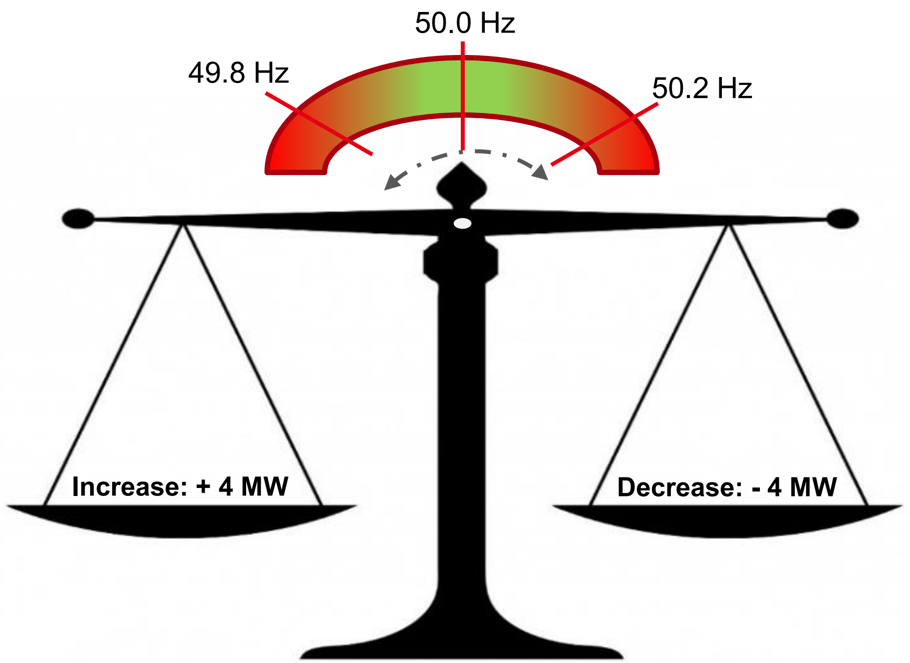
- **Hybridise the turbine unit with a battery to improve capability of providing primary frequency response**
- **Contribute to frequency response with high-dynamic response**
- **Significantly reduce turbine wear and tear and quantify it**
- **Evaluate the possibility of upgrading fixed speed Kaplan turbin to variable speed**

x4 35MW RUN-OF -RIVER BATTERY/ TURBINE HYBRID TECHNOLOGY 1959

VOGELGRUN DEMONSTRATOR

Technical constraints of the project:

- **Frequency Containment Reserve FCR is fixed to 10% of nominal power → Power FCR = 4 MW**
  - For a frequency deviation of -200 mHz
    - HPP increases of 4 MW from the current production power
  - For a frequency deviation of +200 mHz
    - HPP decreases of 4 MW from the current production power
- **Battery are installed for a duration of 2 years**



SIZING METHODOLOGY OVERVIEW

Methodology consists in two major steps:

1. **Sizing BESS**
   - Determine the power of inverter
   - Determine the capacity of battery

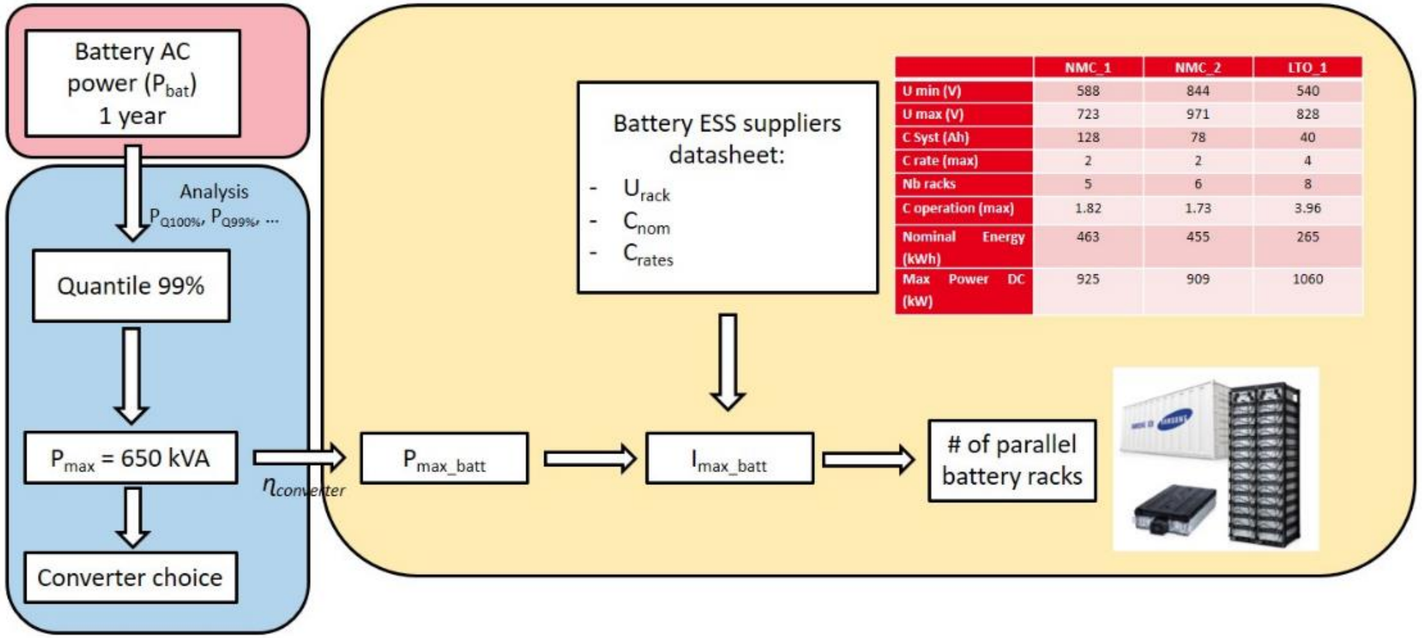
2. **Computing indicators**

   Make simulation for different manufacturers & technologies → selecting the optimum solution

BESS SIZING METHODOLOGY OVERVIEW

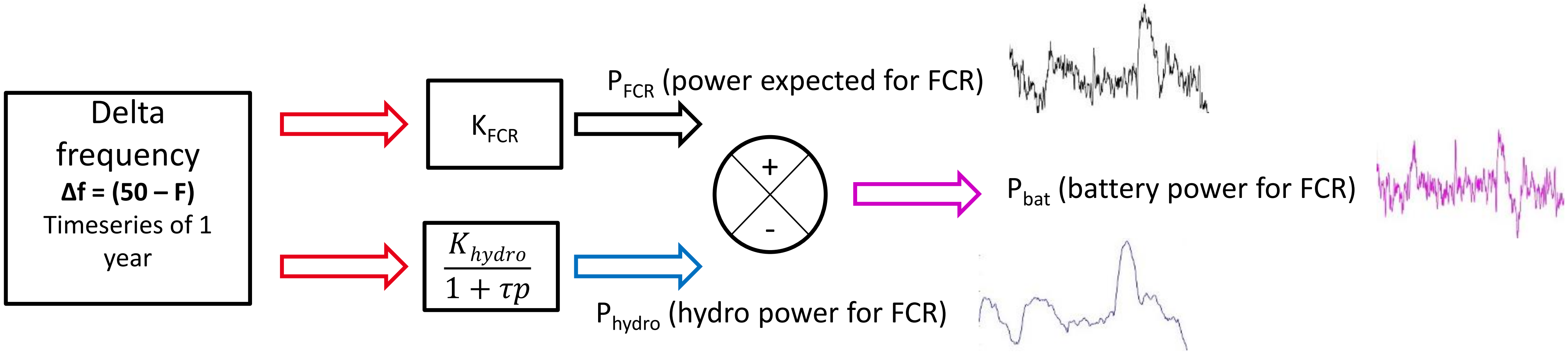
Methodology consists in 3 major steps:

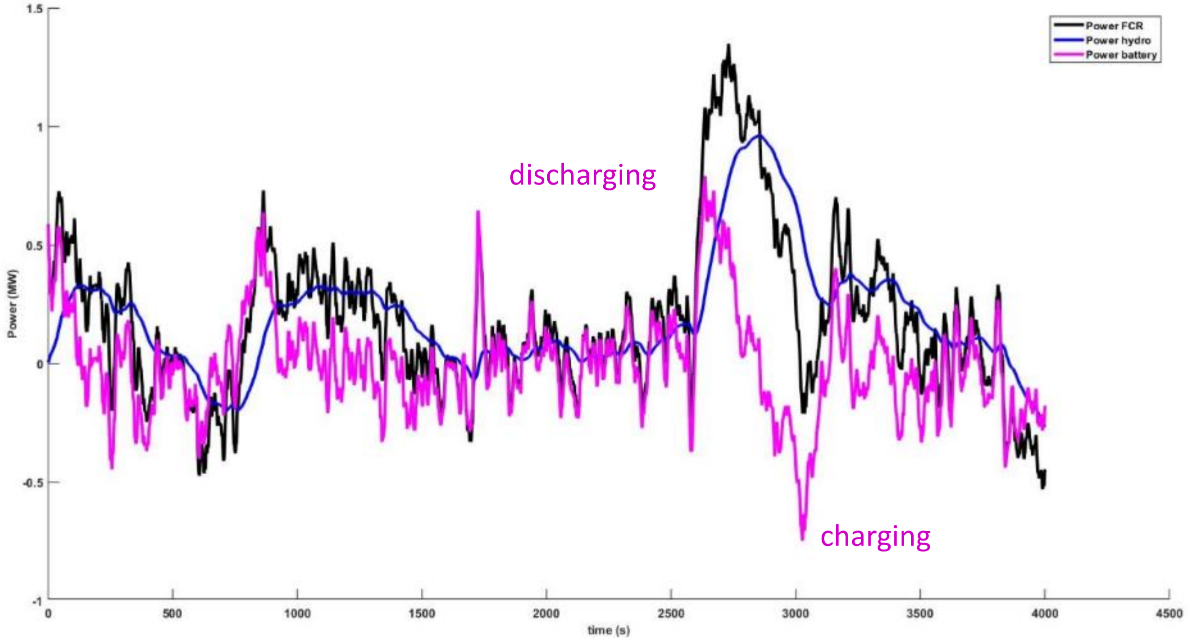
- Assess the power profile applied to Battery Energy Storage System
- Analysis of this profile to determine maximum power of the inverter
- Calculate current profile and capacity for different technologies and manufacturers regarding product specifications



	NMC_1	NMC_2	LTO_1
U min (V)	588	844	540
U max (V)	723	971	828
C Syst (Ah)	128	78	40
C rate (max)	2	2	4
Nb racks	5	6	8
C operation (max)	1.82	1.73	3.96
Nominal Energy (kWh)	463	455	265
Max Power DC (kW)	925	909	1060

BESS'S POWER PROFILE DERIVED FROM FREQUENCY DATA



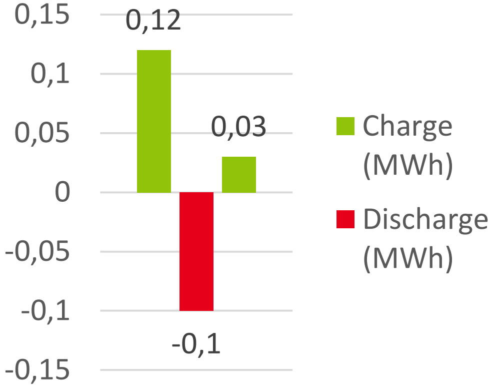


K_{FCR}= Power max for FCR / 200mHz
K_{hydro}= K_{FCR}
τ = 115s (HPP's response time constant for Vogelgrun)

BESS'S POWER PROFILE ANALYSIS

Maximum power over 1 year

indicators example



= 0.12+0.03 = 0.15 MWh

= 0.1 MWh

= 0.15-0.1 = 0.05 MWh

	HPP model = 1er ordre T=115s						
Quantile	100%	99%	98%	97%	96%	95%	90%
BESS Pmax Charge (MW)	1.96	0.65	0.54	0.49	0.45	0.43	0.35
BESS Pmax Disharge (MW)	2.89	0.65	0.54	0.49	0.45	0.43	0.35
Max daily charge Energy (MWh)	2.05	2.04	2.03	2.02	2.00	1.99	1.93
Max daily discharge Energy (MWh)	2.05	2.01	1.98	1.96	1.94	1.93	1.85
Max Delta E/day (MWh)	0.05	0.08	0.09	0.10	0.10	0.11	0.12
Over 15 kW/s (%)	0.008	0.604	1.18	1.76	2.33	2.9	5.73

BESS CAPACITY SIZING

Battery AC power (P_{bat}) 1 year

Analysis $P_{Q100\%}$, $P_{Q99\%}$, …

Quantile 99%

P_{max} = 650 kVA

$\eta_{converter} = 95\%$

P_{max_batt}

Battery ESS suppliers datasheet:

- U_{rack}
- C_{nom}
- C_{rate}

	NMC_1	NMC_2	LTO_1
U min (V)	588	844	540
U max (V)	723	971	828
C Syst (Ah)	128	78	40
C rate (max)	2	2	4
Nb racks	5	6	8
C operation (max)	1.82	1.73	3.96
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I_{max_batt}

$$I_{max} = \frac{Pmax\_batt}{Umin}$$

# of parallel battery racks

$$N_{Racks} = \frac{Imax\_batt}{Csyst * Crate}$$

BESS CAPACITY SIZING

Pmax_ac inverter (kVA)	650
Efficiency AC/DC	95%

	NMC_1	NMC_2	LTO_1
Umin (V)	588	844.8	540
Unom(V)	723	971	828
C_sys (Ah)	128	100	40
C rate cont	2	2	4
C rate pulse	2.5	2.5	8
Nb Rack	5	5	8
C max cont	1.82	1.62	3.96
Energy (kWh)	463	486	265
Pmax (kW)	925	971	1060

- LTO technology allows to perform the battery with high power rate (4C versus 2C for NMC technology)
- However the price (€/kWh) of LTO technology is more expensive
- Maintenance and disposal represent significant costs for a BESS

→ Necessity to introduce an ageing indictor

AGING MODELS ARCHITECTURE DEFINITION

Model equations : cumulate calendar and cycling ageing using degradation laws

$$dQ_{loss} = \frac{\partial Q_{loss}}{\partial t} dt + \frac{\partial Q_{loss}}{\partial Q_{th}} dQ_{th}$$

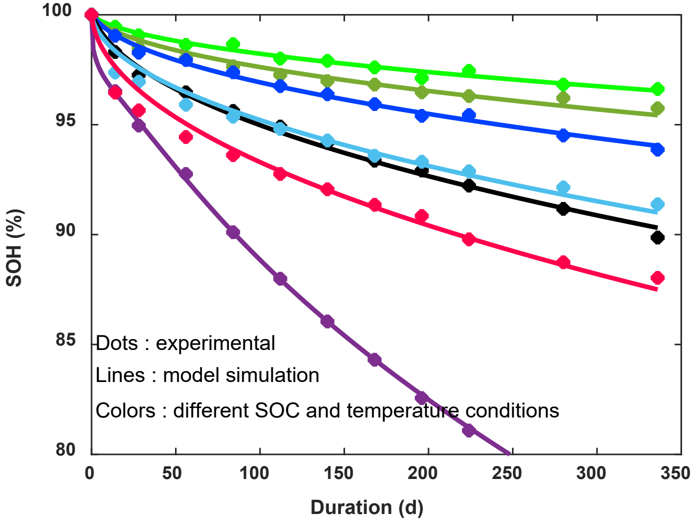
With A and J_{cal} and J_{cyc} to be identified using experiments

Calendar: $$\frac{\partial Q_{loss}}{\partial t} = \frac{J_{cal}}{1 + A.Q_{loss}}$$

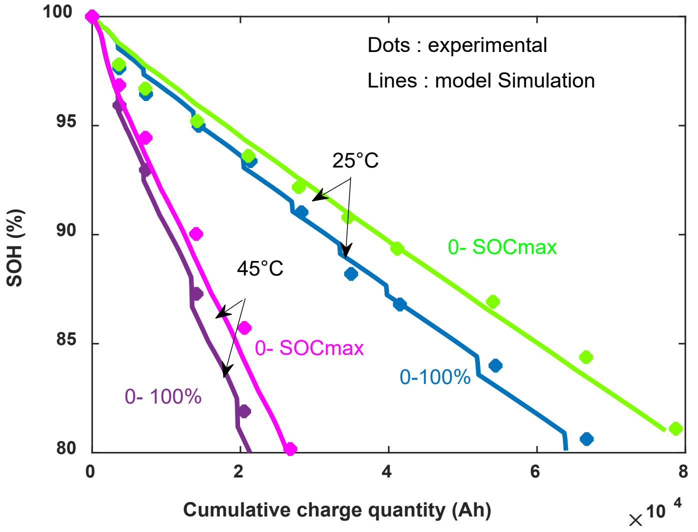
Cycling: $$\frac{\partial Q_{loss}}{\partial Q_{th}} = J_{cyc}$$

Model identification on experimental results

Calendar

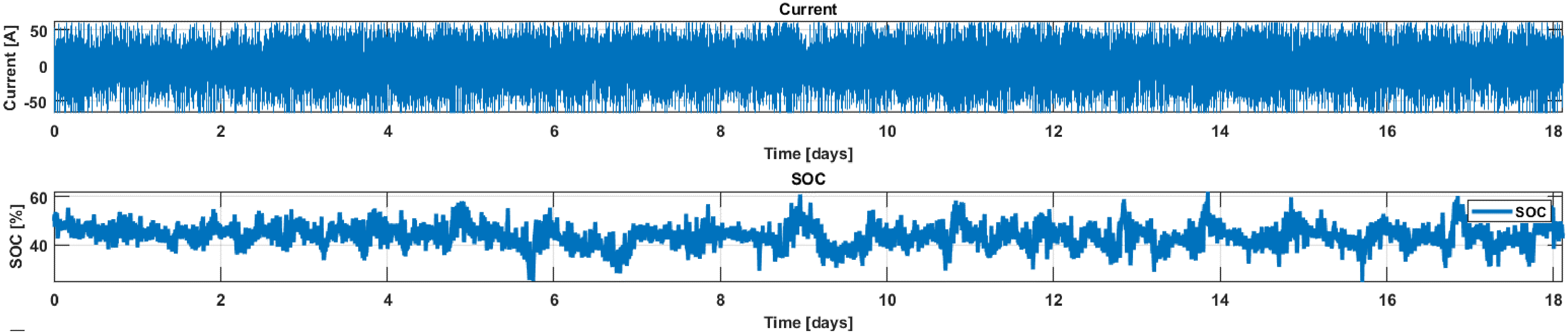


Cycling



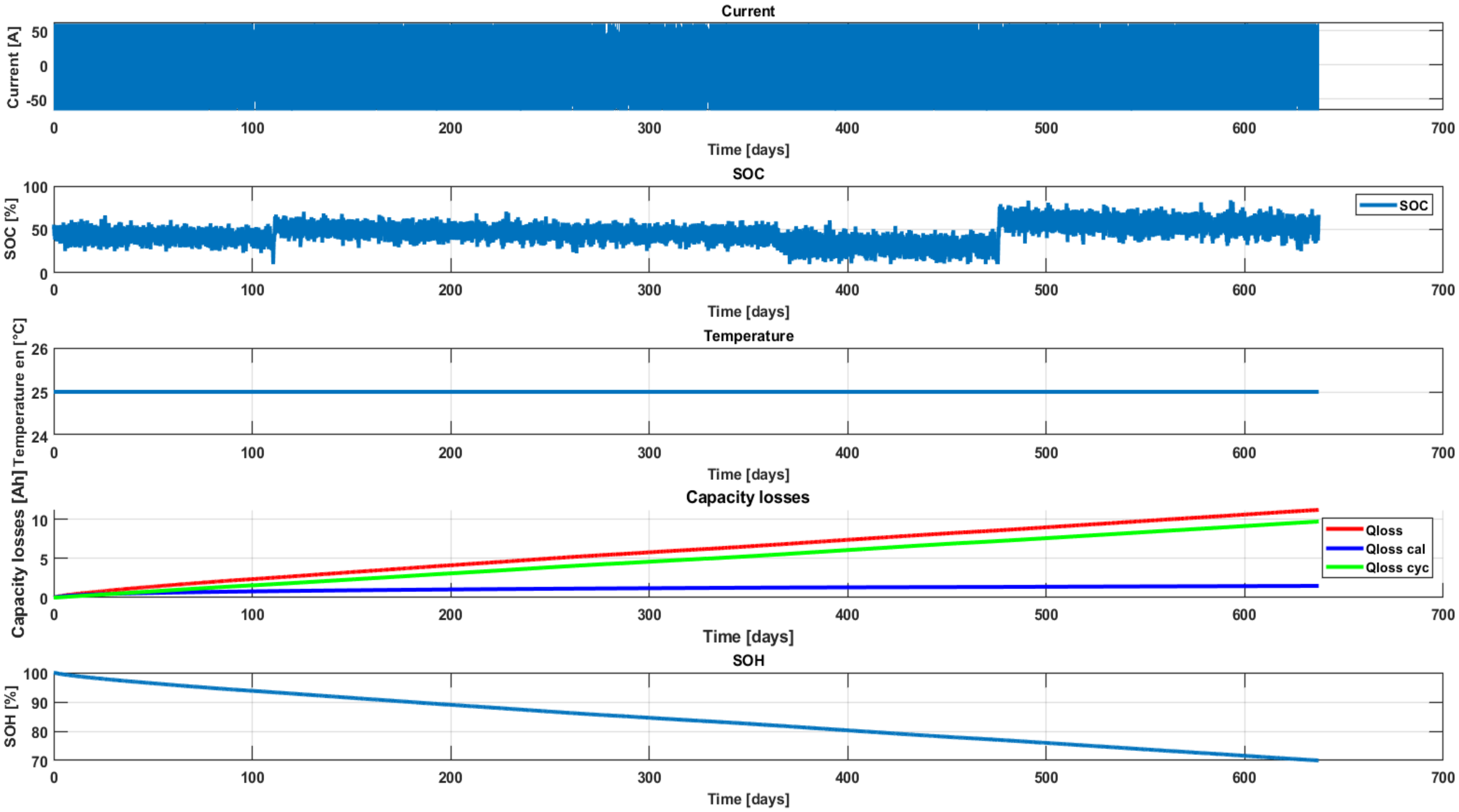
AGEING SIMULATION DEFINITION

- The current profile has been sized regarding cell’s capacity
- SOC profile is calculated taken into account the cell’s degradation
- Cell’s temperature is assumed constant at 25°C (no electro thermal model available at CEA)
- Due to dissymmetric DC profile a Power Management System (PMS) has been designed in order to operate the BESS around a SOC target.



AGEING SIMULATION RESULT

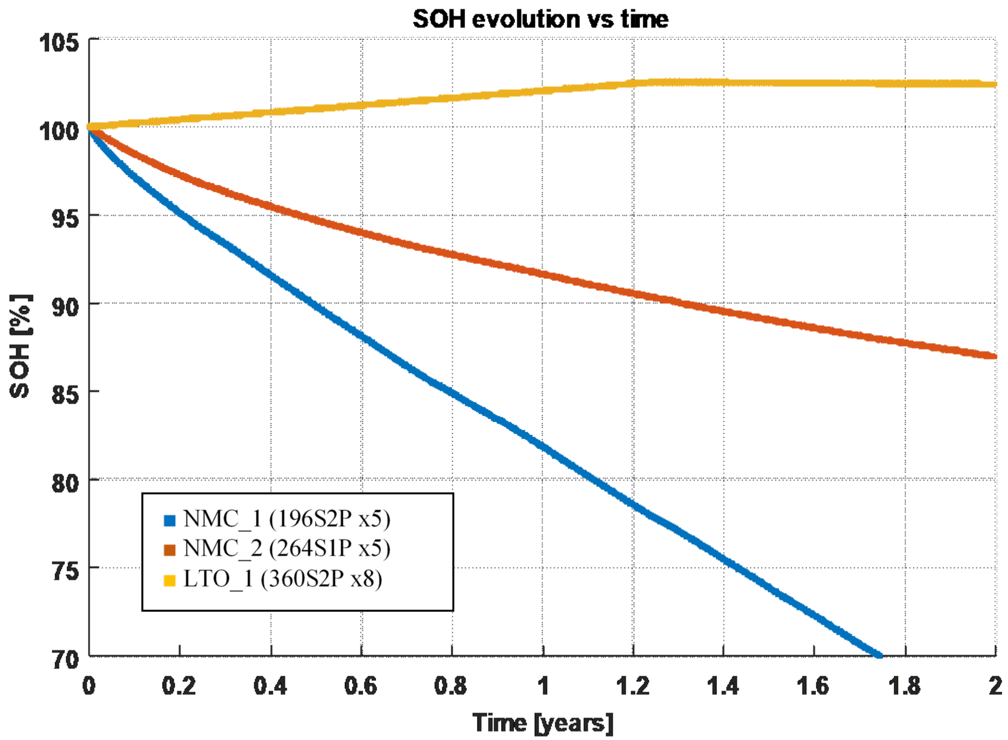
Example of a simulation result obtained with SOC target = 50% on NMC_1 li-ion cell model :



- Current profile at cell level
- SOC profile at cell level
- Temperature profile at cell level
- Capacity losses results:
  - Due to calendar
  - Due to cycling
- SOH profile estimated by the model

AGEING SIMULATION RESULTS COMPARISON

SOH results obtained with SOC target = 50% for 3 different cell references



- A significant difference can be noticed between each cell's references
- LTO_1's models presents a running-in phase that can be usually found on this type of technology before starting a low-speed capacity fade
- NMC_1's models presents the lowest performance
- Degradation models are not accurate for SOH under 70%

CONCLUSION

- **BESS sizing is complete both considering methodology and specific application to Vogelgrun**
- **BESS parameters are computed**
  - Power (650kW) for Power Converter System
  - Capacity for battery (different regarding manufacturer system)
- **Titanate battery technology show very good ageing behavior**
  - But the price per kWh is the more expensive
- **Manganese battery technology (NMC_2 manufacturer)**
  - Price is cheaper
  - SOH (87%) remains acceptable after 2 years with an initial capacity about 500 kWh in total

ACKNOWLEGMENT

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- **INES.2S**

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