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# REDOX FLOW BATTERIES AT CEA-LITEN: TEST FACILITIES, SOME EXAMPLES OF CHARACTERIZATION AND FEEDBACK

Annual Scientific Meeting of the GDR RFB, 3 and 4 November 2021 – Paris

| Nicolas Guillet

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Annual Scientific Meeting of the GDR RFB 3 and 4 November 2021 – Paris

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Institut National de l'Énergie Solaire (INES)



~ 450-500 persons



~ 70 patents per year



200 industrial partners



Budget ~ 60 M€



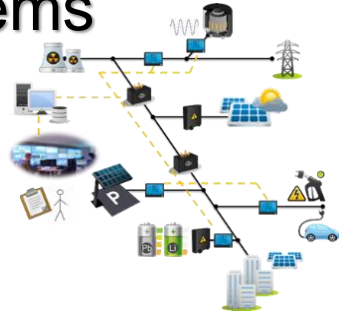
## Photovoltaic



material  
cells  
modules  
equipment  
process

## Systems

software  
electronics  
storage  
grid  
mobility & loading



## Building

thermal systems  
envelope  
management



# ELECTROCHEMICAL STORAGE OF ENERGY

- Three main domains addressed by the laboratory

## Stand-alone systems



## Grid-connected systems



## Building integration



- Selection of the most appropriate battery
- Definition of advanced management strategies

- Tests & characterization of batteries



- Small size (up to 20 V, 10 to 800 A) → 280 channels
- Module size (up to 150 V and 800 A) → 40 channels
- Pack size (up to 800 V and 600 A – 250 kW max) → 12 channels

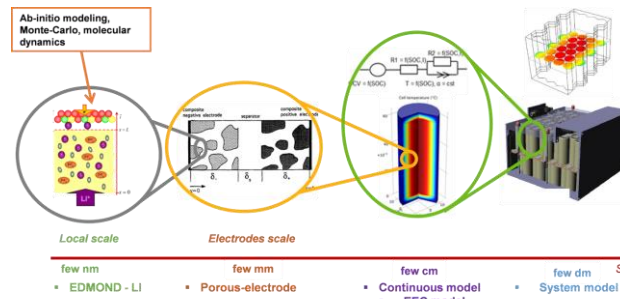
- Battery monitoring & management

## Benchmarking

- Performance
- Durability
- Safety

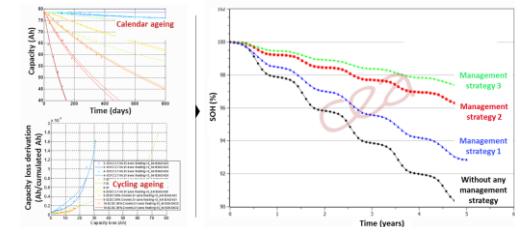


## Ageing modelling



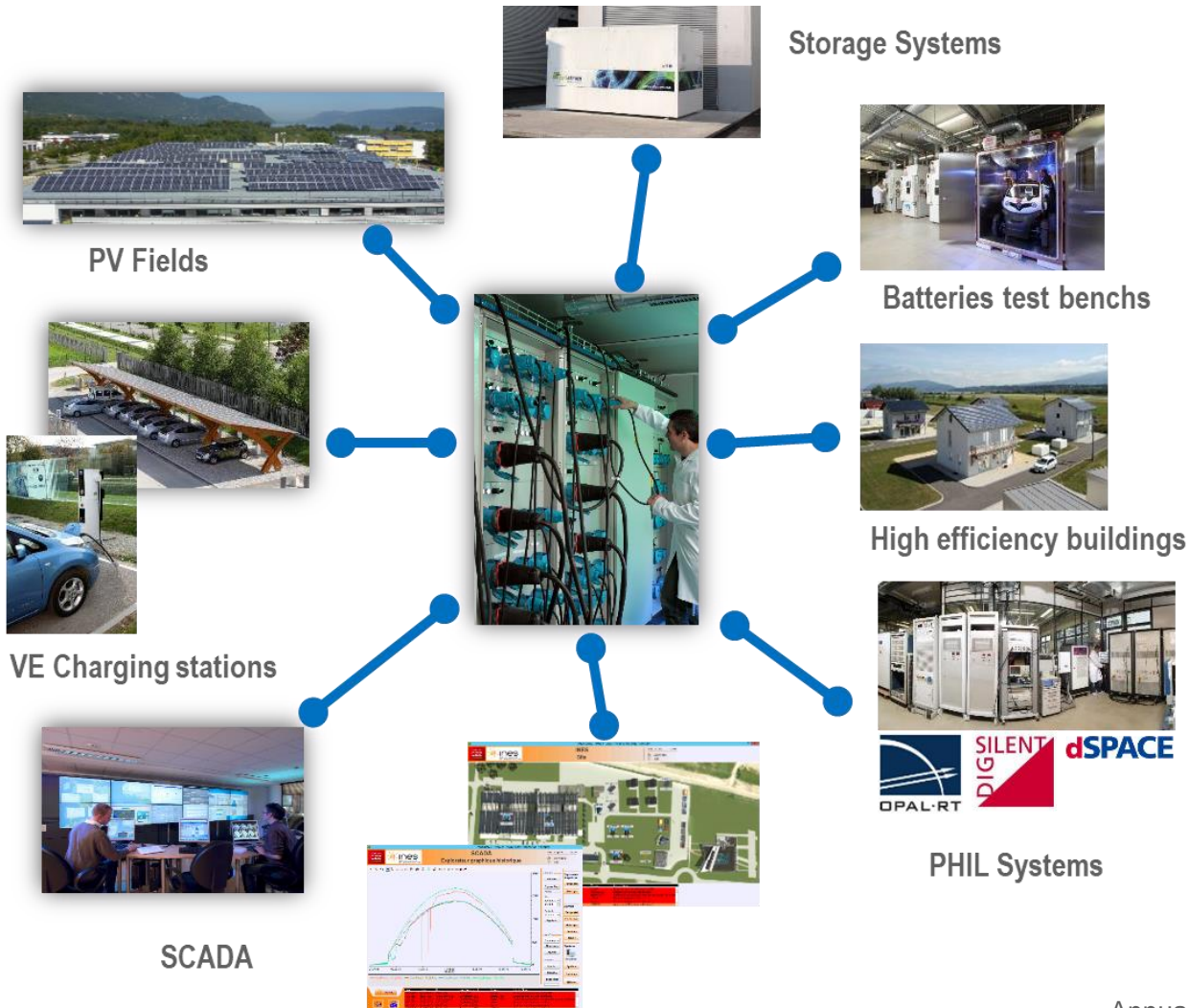
## Management algorithms

Optimization of operating strategies



# TESTS FACILITIES AT INES CAMPUS

- **EMS microgrid platform**

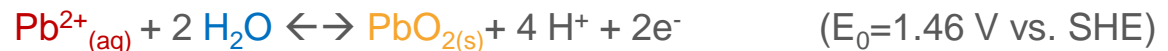
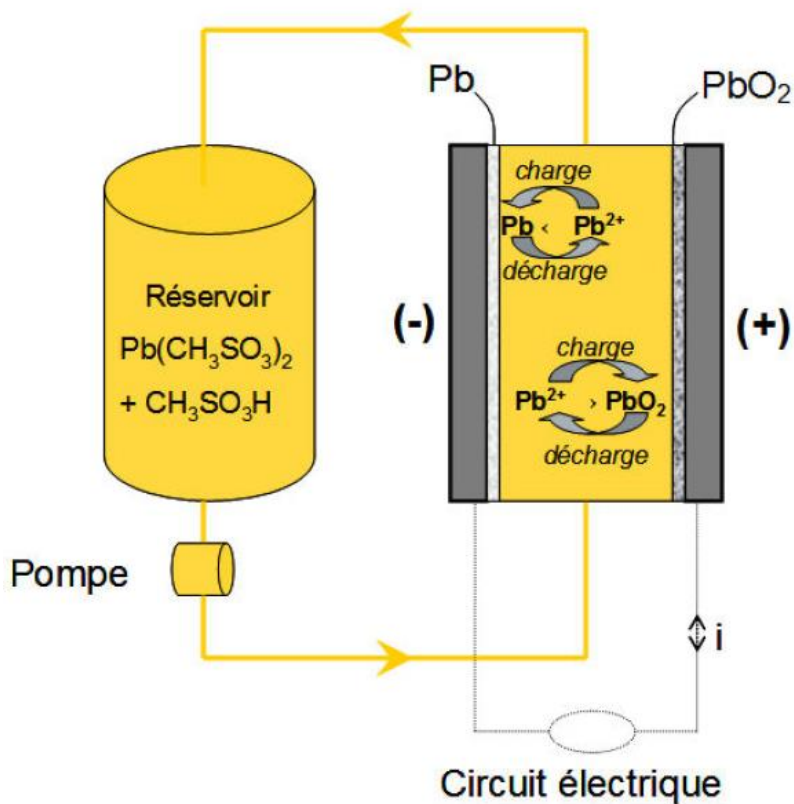


## Objectives

- ✓ **Functional tests on equipments**
  - ✓ **EMS algorithms development and validation**
  - ✓ **Smart Charging tests/ V2G / V2H**
- **170 kVA connection to “Public Grid”**
  - **6 AC LV Bus bars (400 VAC)**
  - **45 kVA AC Grid simulation**
    - 3 Ph 120V-690V
    - 0-2500 Hz fundamental / Up to 50 kHz Harmonics
    - PHIL Simulations
  - **BESS characterization and control development**
    - 3 test channels for BESS (on/off grid)
    - Up to 250A @400V
    - 600A Bus bar with islanding capabilities
  - **110 kWc configurable PV fields**
  - **120 kWc PV simulation**
  - **100 kW batteries simulation**
  - ...

# FEEDBACK ON SYSTEMS WITH VARYING DEGREES OF TECHNOLOGICAL MATURITY

- Lead soluble - methanesulfonic acid type redox battery – Pb-MSA (Lab. scale)



OCV ~ 1.6 V, solubility of  $\text{Pb}(\text{CH}_3\text{SO}_2)_2$  in MSA ~ 2 mol/L

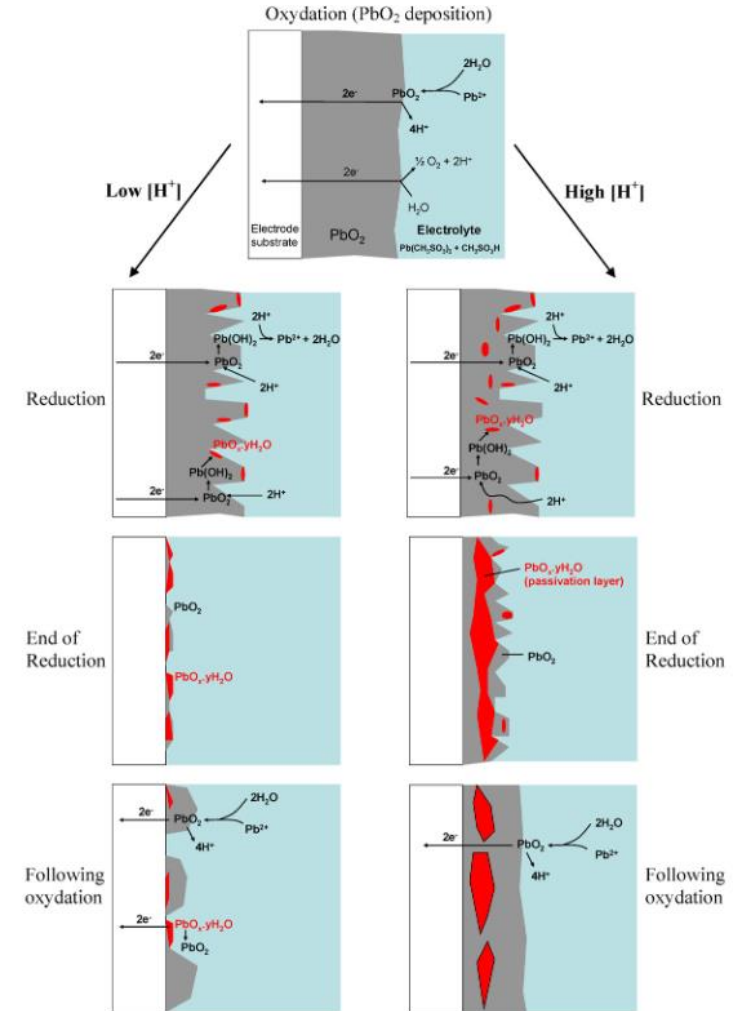
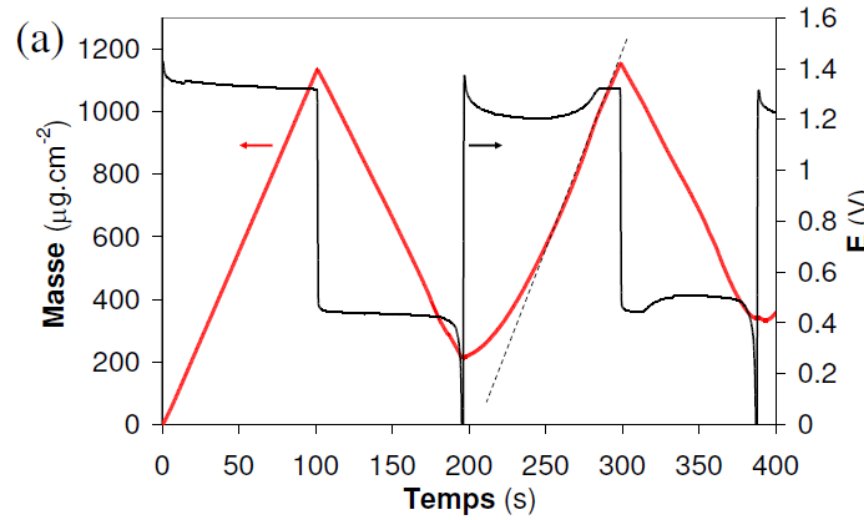
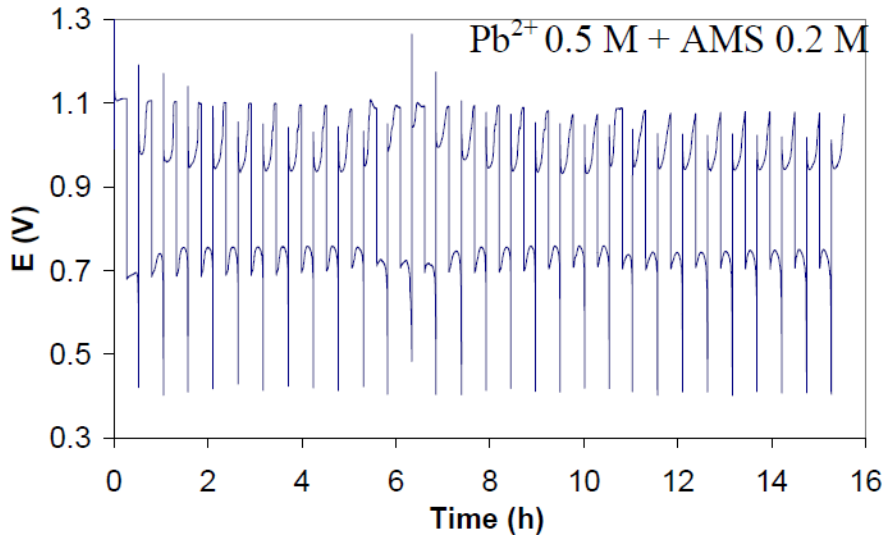
## Advantages :

- High theoretical active lead fraction (> 80 %)
- Membraneless (low cost)
- Solid  $\leftrightarrow$  aqueous species reaction : no solid phase evolution

## Hurdles :

- Low kinetic of  $\text{PbO}_2/\text{Pb}^{2+}$  couple; high overpotentials
- Incomplete reduction of  $\text{PbO}_2$  ; build-up of  $\text{PbO}_2$  at both electrodes
- Poor  $\text{PbO}_2$  adherence ; loss of  $\text{PbO}_2$  particles in the electrolyte

- Lead soluble - methanesulfonic acid type redox battery – Pb-MSA (Lab. scale)



Oury et al. / Electrochimica Acta 71 (2012) 140–149  
<http://dx.doi.org/10.1016/j.electacta.2012.03.116>

- Limitations:**

- $O_2$  evolution during charge
- Irreversible solid state reaction  $PbO_2 \leftrightarrow PbO_x$
- $PbO_x$  acts as a passivation layer when  $[H^+] > 1 \text{ mol/L}$



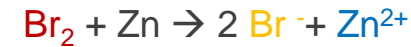
- Zinc – Bromine (Redflow)



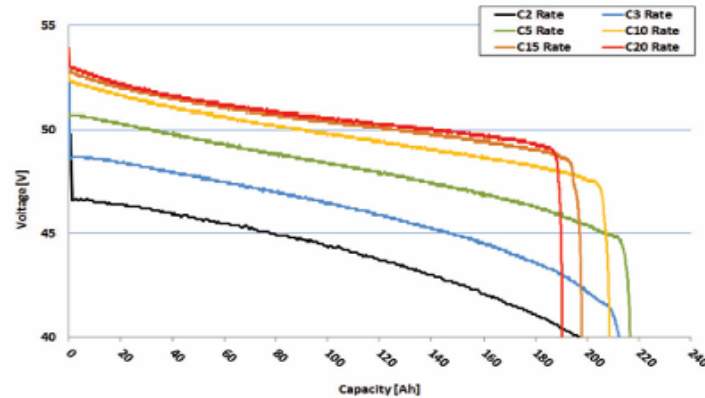
Positive :



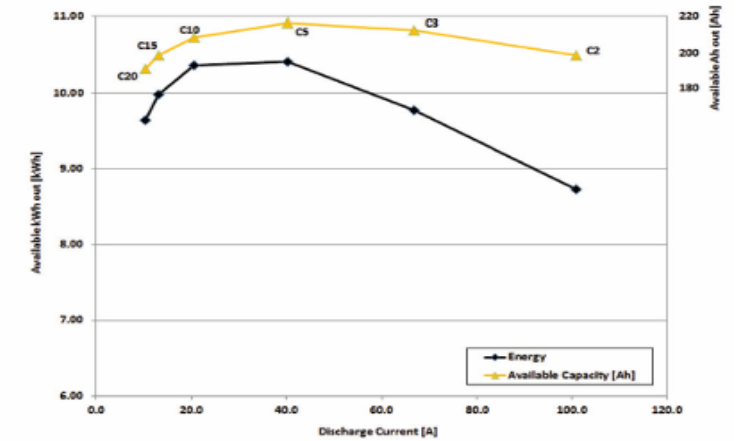
Negative :



DISCHARGE - CAPACITY CURVES



ENERGY - CAPACITY CURVES



Power / energy capacity : 5 kW (7.5 kW peak) / 11 kWh

Voltage application : 53 Vdc

Net energy efficiency : 80% DC-DC Max

**Dimensions / weight**

845 L x 823 H x 400 W (mm)

90 kg without electrolyte

240 kg with electrolyte (100L)

Internal operating temperature : 10-50 °C

- Advantages :**

- Good specific energy density and round trip efficiency
- 100 % depth discharge available

- Hurdles :**

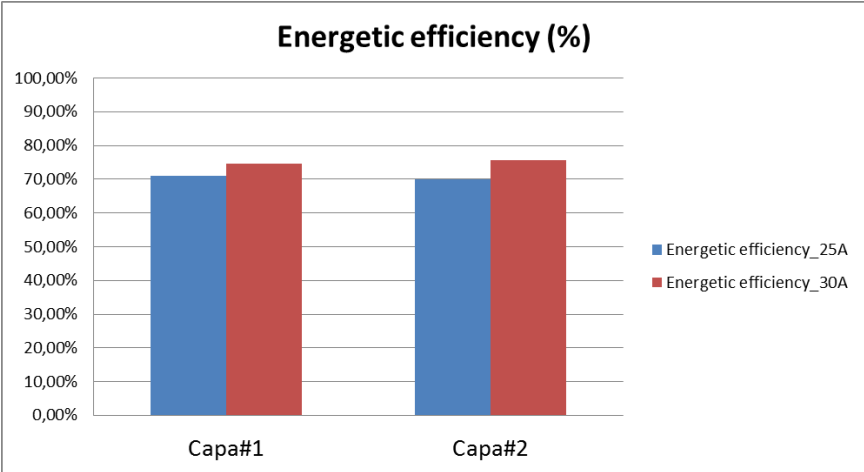
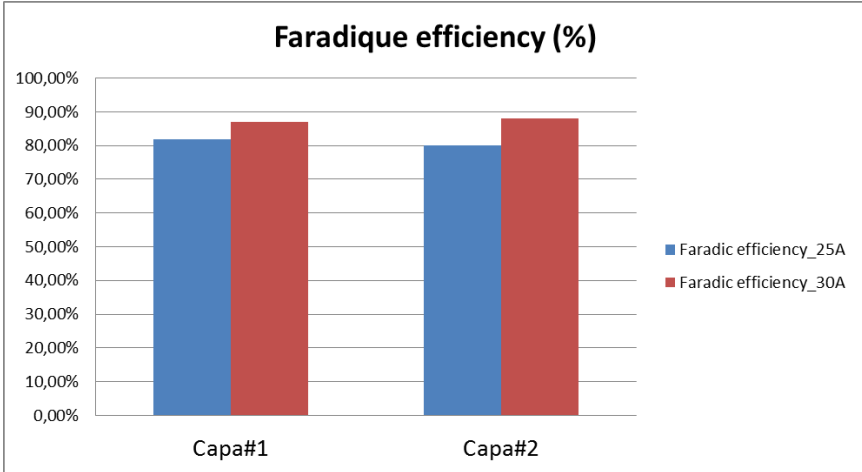
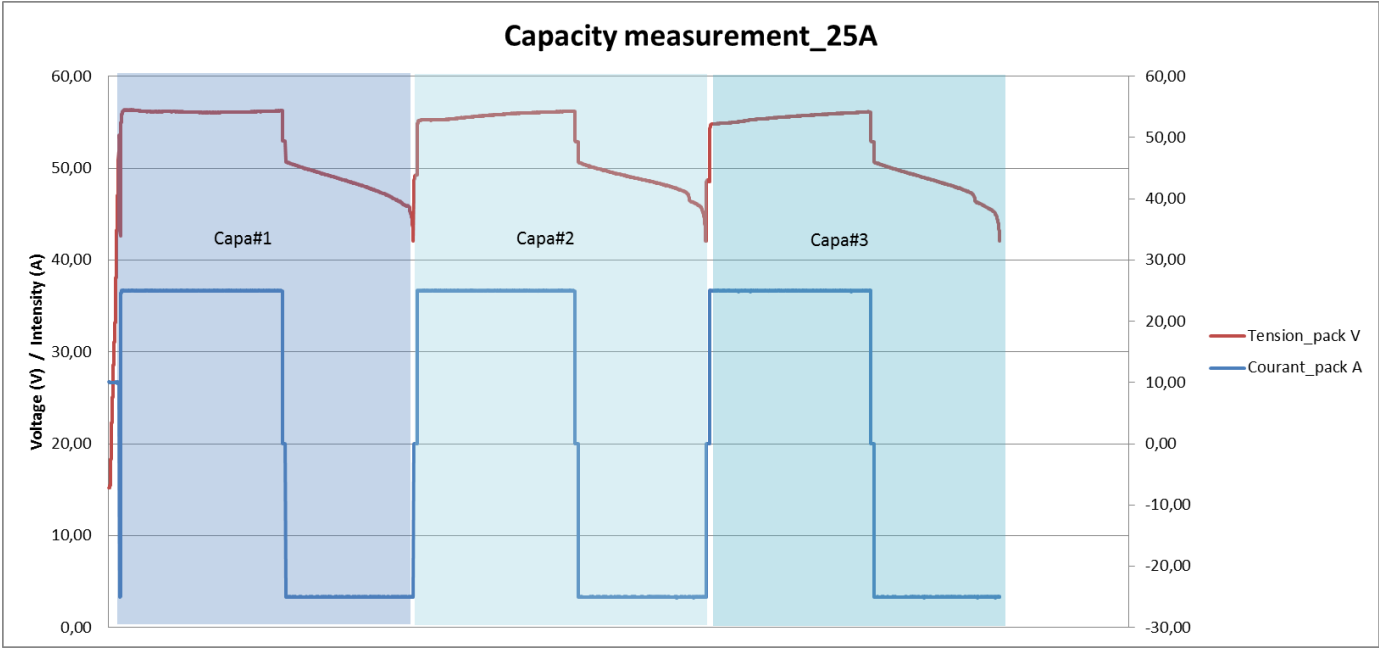
- Self discharge
- Zinc dendrites formation

# FEEDBACK ON SYSTEMS WITH VARYING DEGREES OF TECHNOLOGICAL MATURITY

- Zinc – Bromine (Redflow)



Power / energy capacity : 5 kW (7.5 kW peak) / 11 kWh



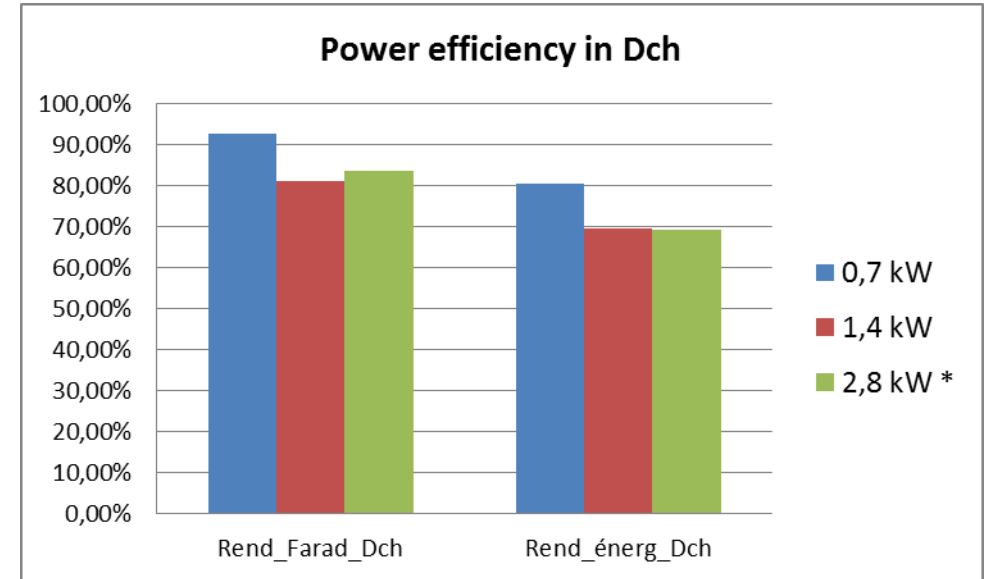
# FEEDBACK ON SYSTEMS WITH VARYING DEGREES OF TECHNOLOGICAL MATURITY

- Zinc – Bromine (Redflow)



Power / energy capacity : 5 kW (7.5 kW peak) / 11 kWh

- Efficiency:



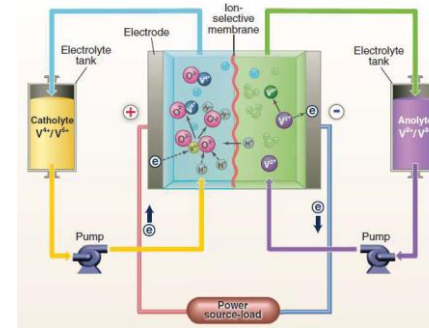
- Self discharge : SoC decreases linearly with time > 1 %/h at 25 °C

- **Limitations:** works very well but

- Balance of système is a major cost element
- System design and energy management system had to be improved
- Periodic self maintenance (minimum once every 72 hours of zinc pump operation)

# FEEDBACK ON SYSTEMS WITH VARYING DEGREES OF TECHNOLOGICAL MATURITY

- All Vanadium redox flow battery (VRB)



Noak et al., 2020

- Advantages :**
  - Simple system
  - 100 % depth discharge available
- Hurdles :**
  - Self-discharge
  - Low specific density
  - Cost of vanadium

# FEEDBACK ON SYSTEMS WITH VARYING DEGREES OF TECHNOLOGICAL MATURITY

- All Vanadium redox flow battery (VRB)

	Parameter	Data from supplier
Performance	P charge nominale 15 - 80% SOC	10 kW DC 15 kVA onduleur
	Nominal energy	100 kWh
Voltage output	AC voltage	400 V <sub>AC</sub>
	DC voltage range	36V <sub>DC</sub> - 63V <sub>DC</sub>
Efficiency	Round trio DC efficiency	70-80%
Self-discharge	Within Cells	0,07 kW
	Within tankks	Not significant
Weight & size	Size (mm)	4500*2200*2403
	Empty mass	3500 kg
	Mass with electrolyte	10300 kg

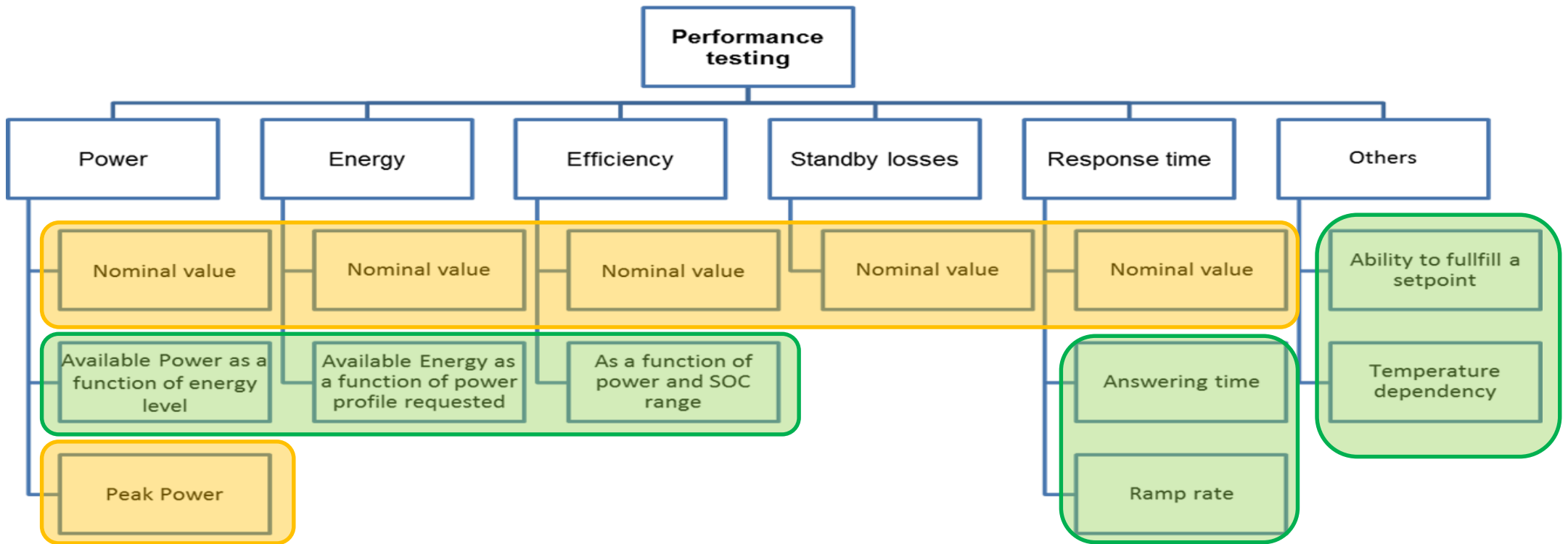


- Cell: 1,2 V / 50 W
- Module (20 cells - 20S) : 24 V / 1 kW
- Battery (10 modules - 2S5P) : 48 V / 10 kW

# FEEDBACK ON SYSTEMS WITH VARYING DEGREES OF TECHNOLOGICAL MATURITY

- All Vanadium redox flow battery (VRB)

- Tests according to the DERri protocol [http://www.der-lab.net/downloads/noe\\_003\\_grid\\_connected\\_storage.pdf](http://www.der-lab.net/downloads/noe_003_grid_connected_storage.pdf)

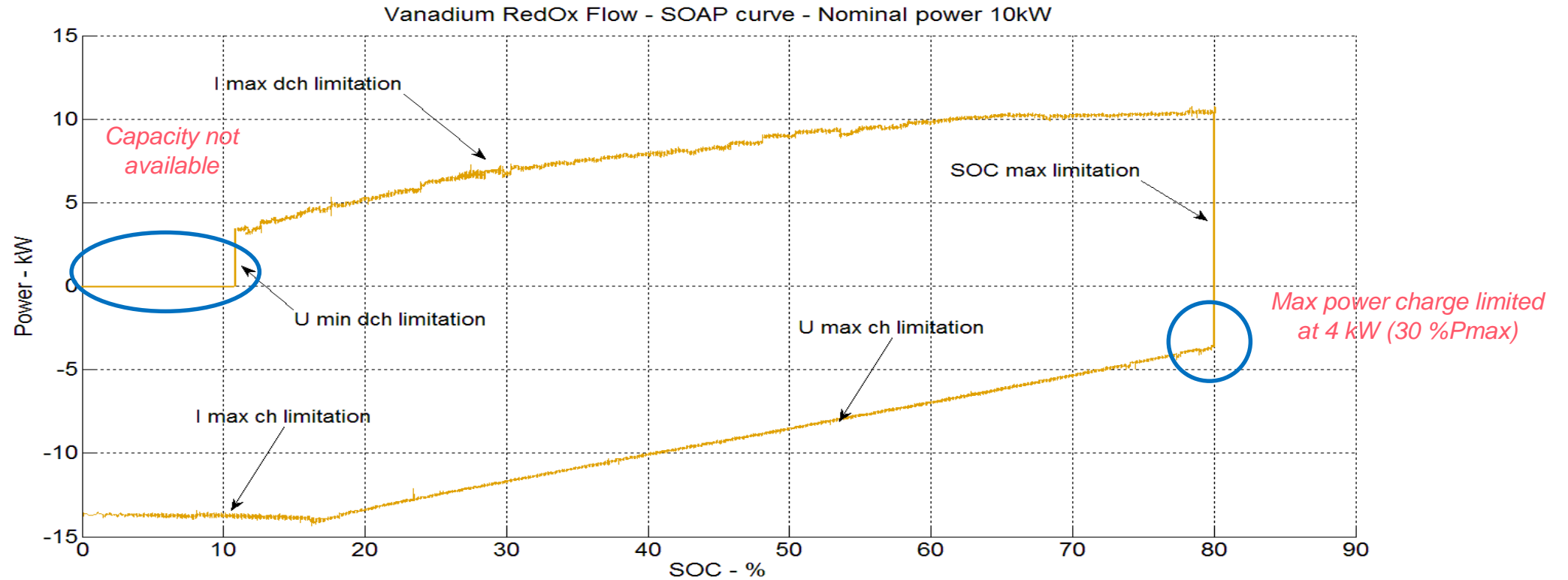


  Data often given by the supplier but have to be confirmed on the whole operation range

  Not or rarely available ; test to be conducted

# FEEDBACK ON SYSTEMS WITH VARYING DEGREES OF TECHNOLOGICAL MATURITY

- All Vanadium redox flow battery (VRB)
  - Example of DERri test : State of Available Power (SoAP)

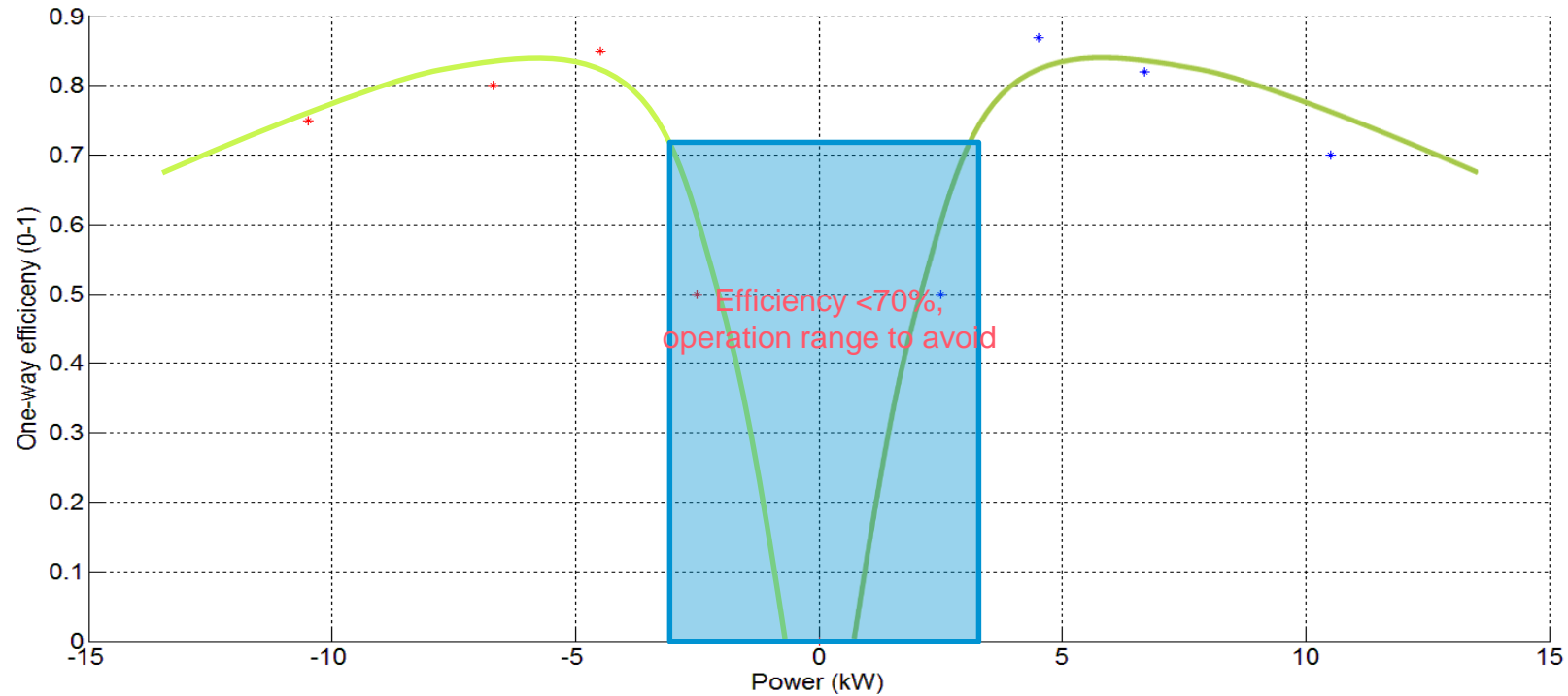


↳ Operation range limited to 0 – 80 % SoC by the BMS

↳ Power limitation with SoC (Umax)

# FEEDBACK ON SYSTEMS WITH VARYING DEGREES OF TECHNOLOGICAL MATURITY

- All Vanadium redox flow battery (VRB)
  - Example of DERri test : one-way AC efficiency

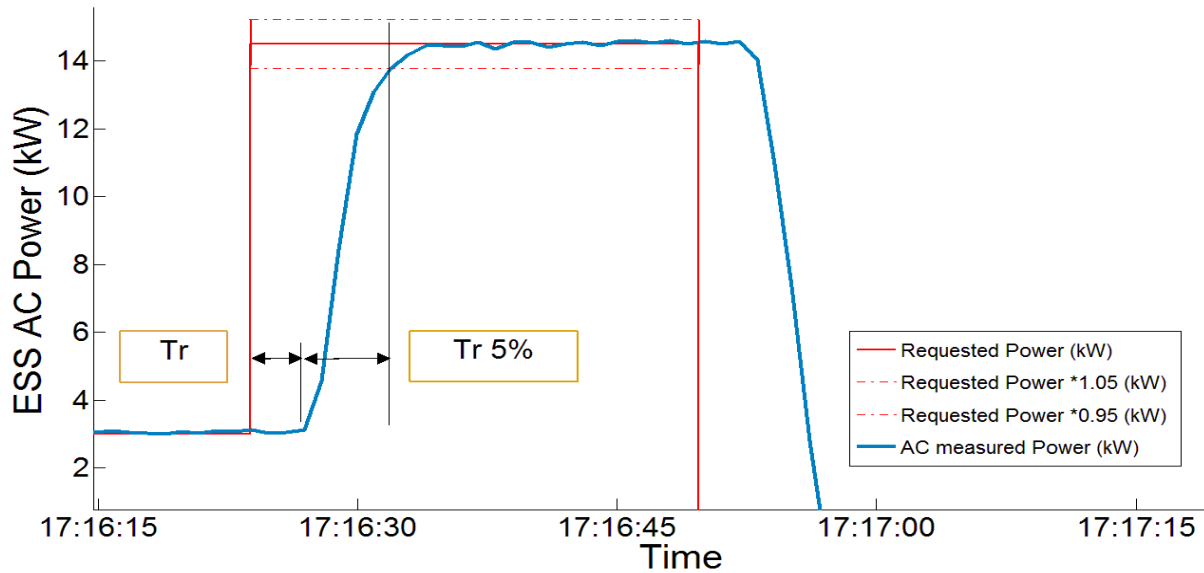


↳ Low AC efficiency at low recharge and discharge rates (auxiliaries)



# FEEDBACK ON SYSTEMS WITH VARYING DEGREES OF TECHNOLOGICAL MATURITY

- All Vanadium redox flow battery (VRB)
  - Example of DERri test : time response

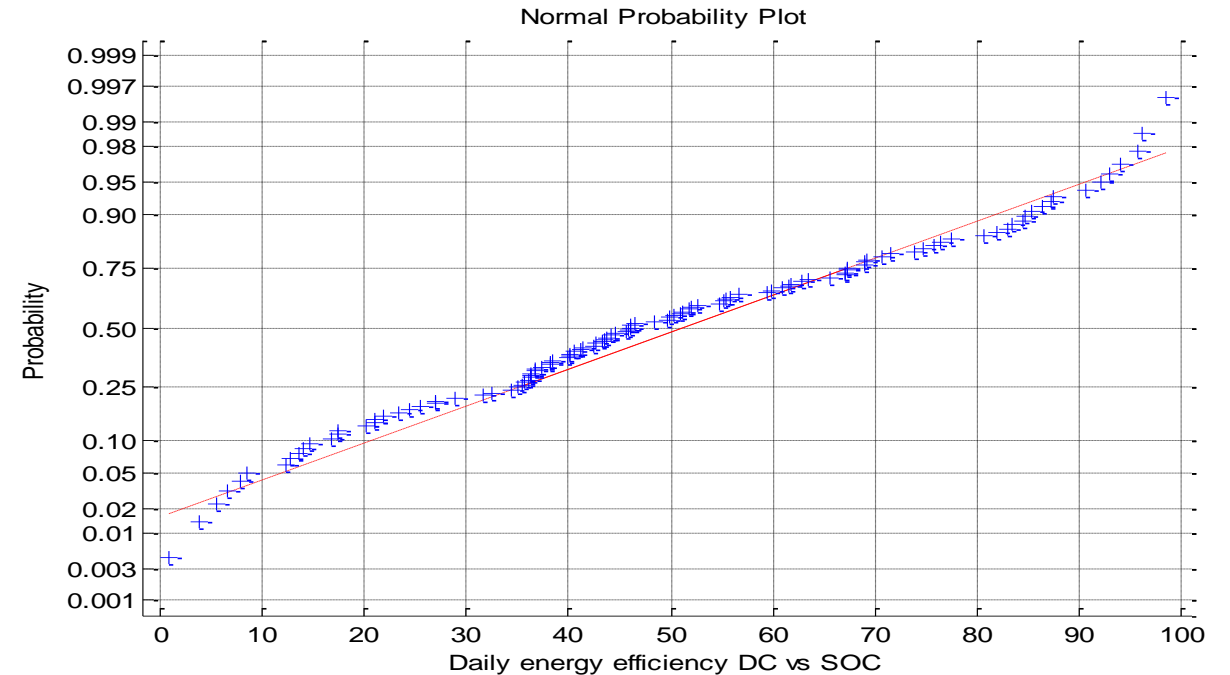
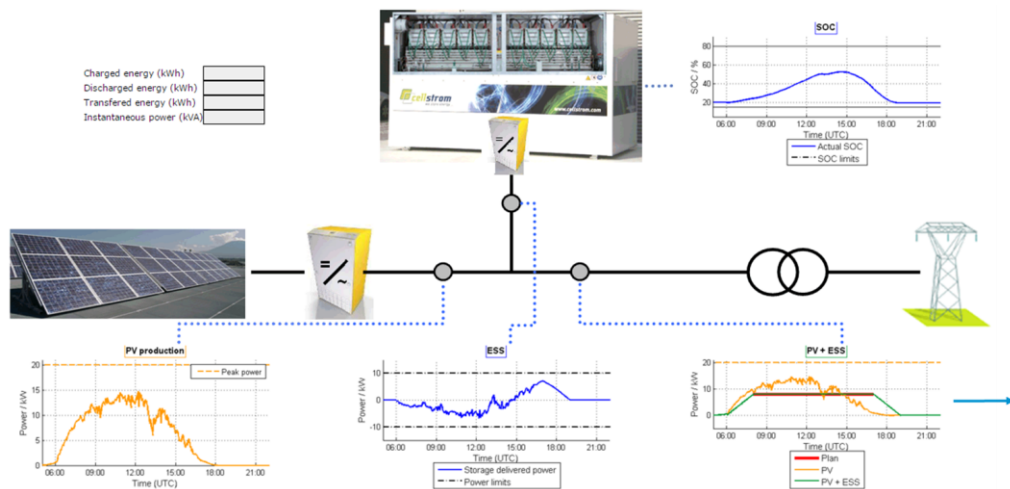


From / to	10 kW charge	10 kW discharge
10 kW charge	-	10s
2kW charge	5s	7s
STOP	8s	8s
2 kW discharge	6s	5s
10 kW discharge	9s	-

↪ Time constants of few seconds

# FEEDBACK ON SYSTEMS WITH VARYING DEGREES OF TECHNOLOGICAL MATURITY

- All Vanadium redox flow battery (VRB)
  - Onsite experiment (Projet AO CRE 2012 PV ZNI) : 500 days of operation



- No evolution of performance during 500 days of operation
- No evolution of the DC efficiency but slight increase of the internal impedance
- 50% of operation points are at an efficiency lower than 50% → operation at low power

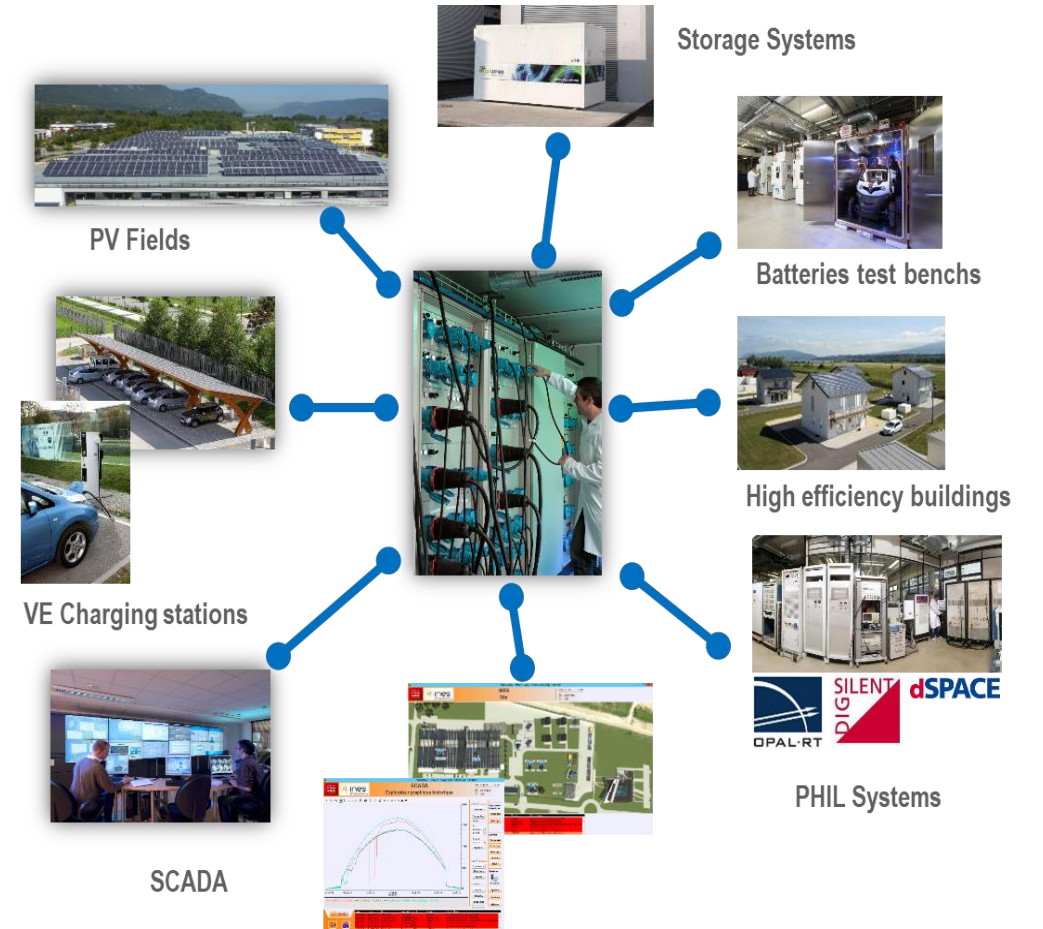
- All Vanadium redox flow battery (VRB)

## Conclusions over 3 years of evaluation

- Strong deviation between standard datasheet and the real life
- Power limitations are mostly related to electrochemical phenomena
- Efficiency is lower than expected and is highly depending on the power request
- OPEX higher than expected (maintenance, electrolyte leak, pump failure...)
  
- Stable performance over 3 years while there was no temperature regulation of the battery



- Stationary application storage and power grid management
- A complete ecosystem and experts in the field of electrochemical storage
- Characterization and evaluation of redox flow batteries of different levels of maturity





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Thank you for your attention !

Questions ?

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