FINAL WEBINARS
26th April 2022

OSMOSE WP4:
Demonstration of an innovative Hybrid Flexibility Device that provides multiple grid services

Presenters:

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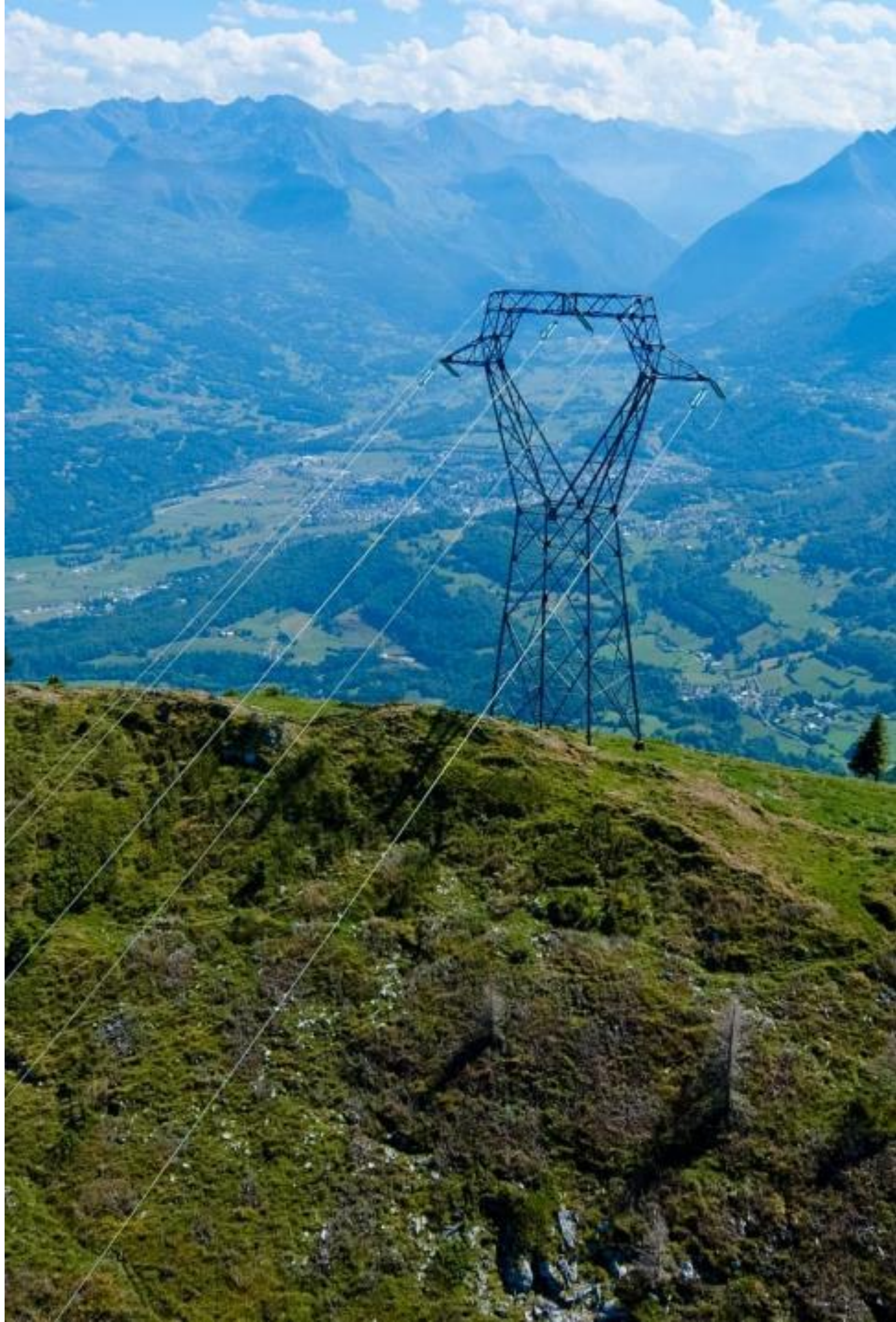
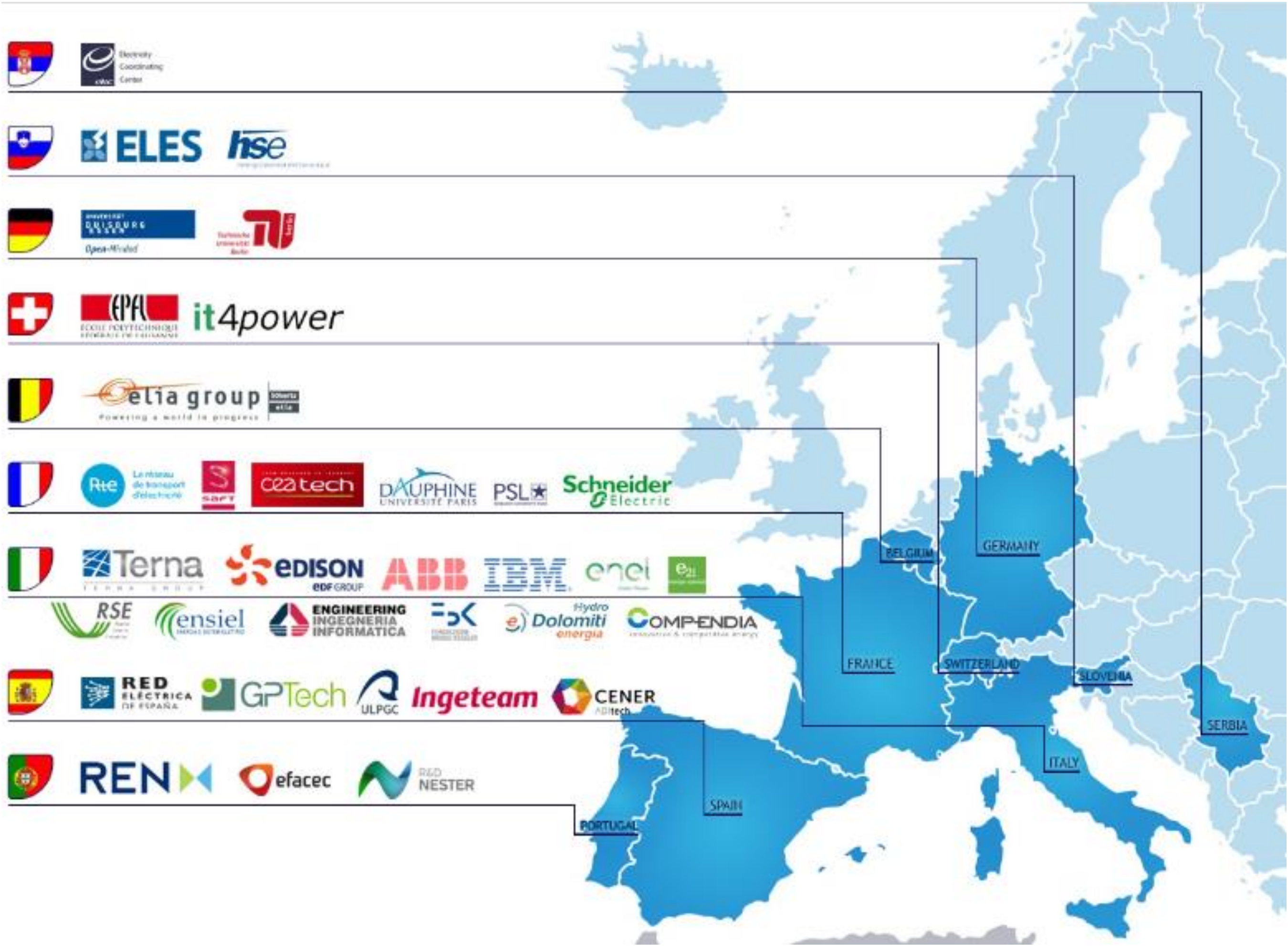
Agenda

1. OSMOSE Project introduction
2. WP4 challenges and objective
3. Demonstrator description
4. Real operation results evaluation
5. Canary islands simulation results
6. Tools for BESS performance analysis
7. Key take aways



The OSMOSE project

- ✓ H2020 EU funded
- ✓ 28M€ budget
- ✓ 33 partners
- ✓ Leaders: **RTE**, REE, TERNA, ELES, CEA, TUB
- ✓ 01/2018 – 04/2022



OSMOSE objectives

- **Improve the understanding of future needs and sources of flexibility** required to achieve the decarbonization of Europe
  - ✓ Modelling and quantification of flexibility in European Long-term scenarios

- Foster the **implementation** of innovative flexible solutions
  - ✓ Large scale demonstrators led by Transmission System Operators (TSOs)
  - ✓ Advanced tools for Battery Energy Storage System operators and power System Operators

Work structure

Simulations of long-term scenarios

- ✓Identify future needs and sources of flexibility
- ✓Develop new tools and methods for flexibility assessment

WP1 Optimal mix of flexibilities

WP2 Market designs and regulations

WP7 Scaling-up and replication

4 Demonstrators

- ✓Foster the participation of new flexibility providers
- ✓Demonstrate new flexibility services and multi-services capabilities

WP3 Grid forming by multi-services hybrid storage

WP4 Multi-services by different storage and FACTS devices

WP5 Multi-services by coordinated grid devices, large demand-response and RES

WP6 Near real-time cross-border energy market

Challenges

- Current policies promote decarbonisation of power generation
- TSOs has the **challenge** of maintaining **stability and security** of isolated or weak power systems with **high penetration of non-dispatchable renewable generation**
- Flexibility services are required to guarantee power system stability and integrate renewable generation
- Effects to mitigate:
  - Rapid changes in renewable energy generation
  - Generation loss incidents and associated imbalance
  - Renewable generation limitations caused by transmission grid congestions

Objective of WP4 demonstrator

Development and demonstration of a Hybrid Flexibility Device (HFD) capable to provide multiple flexibility services to the power grid by coordinated control of different storage systems and static synchronous compensator (STATCOM)

Main contributions:

New hybrid and modular storage solution	• New FACTS device that integrates supercapacitors, lithium-ion battery and modular multilevel STATCOM • Provision of multiple grid services (voltage control, frequency stabilization, oscillations damping, congestion management)
High Voltage Energy Storage	• Development of a lithium-ion battery, voltage up to 1.5 kV in DC • Improve the integration of batteries in the HV grid (reduce losses).
Master Control System for the hybrid flexibility device	• Optimal coordination of hybrid energy storage to provide different flexibility services • Implementation of new control strategies for network operation

Demonstrator

Functionalities to be provided by the demonstrator:

Voltage control

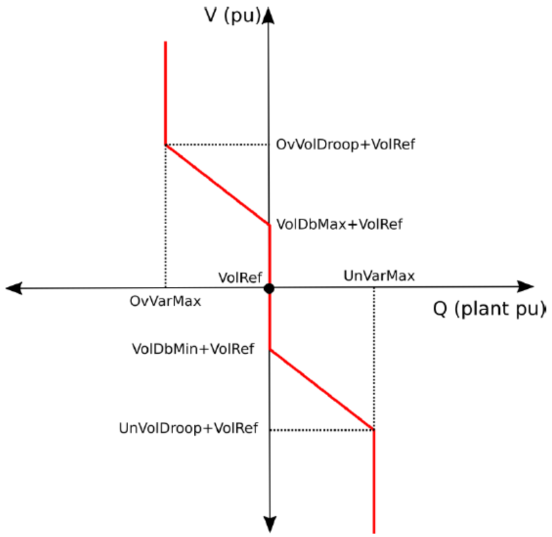
- Voltage set-point
- Reactive power control
- Fast current injection (transient state)

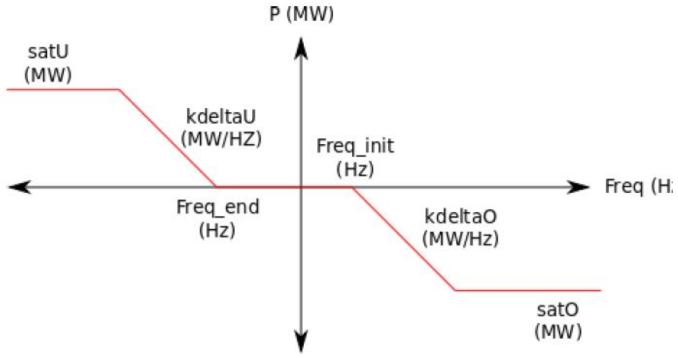
Frequency control

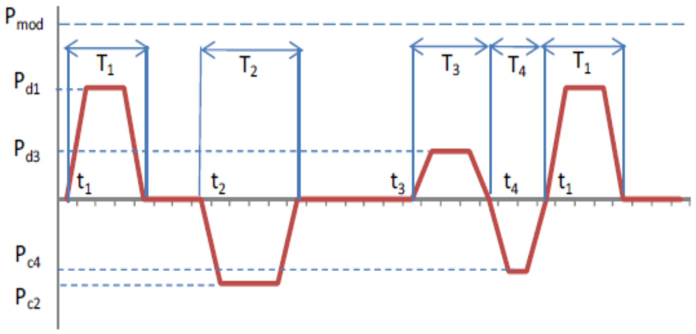
- Inertia emulation proportional to df/dt
- Fast frequency control
- Power-frequency regulation

Others:

- Power oscillation Damping
- Setpoint tracking (P)
- Renewables smoothing
- Congestion Management



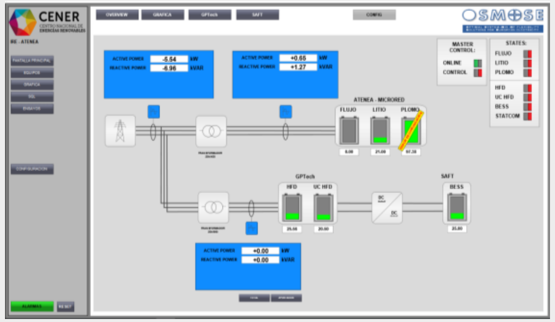




Demonstrator

Demonstrator location and overview:

Demo location:
CENER facilities in Sangüesa, Navarra region (Spain)



SCADA

Master Control

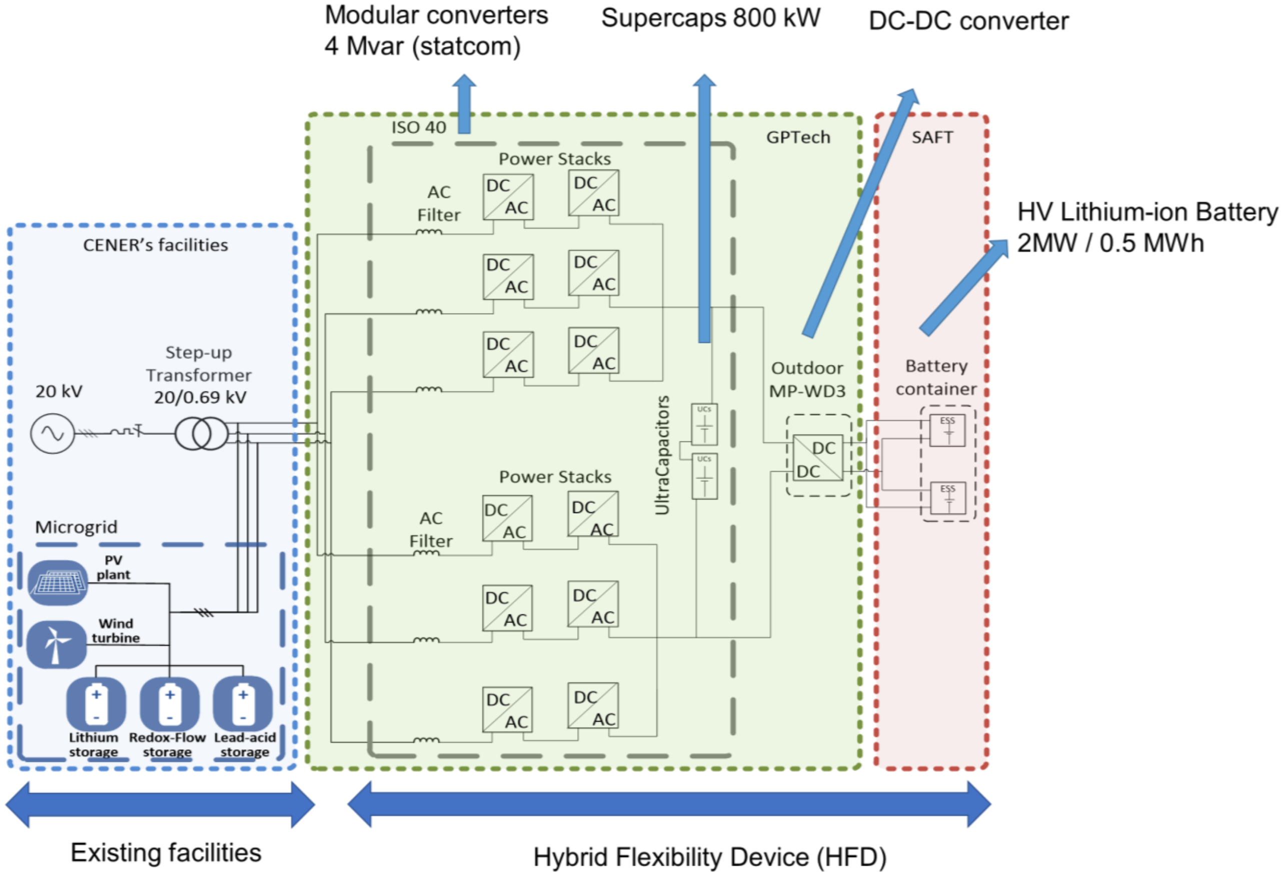
Grid connection 20 kV

ATENEA Microgrid

Hybrid Flexibility Device

Hybrid Flexibility Device

The Hybrid Flexibility Device integrates a modular multilevel STATCOM, supercapacitors and HV Battery storage



Hybrid Flexibility Device

High-Voltage Lithium-ion battery from Saft:

Main Characteristics of the demonstrator:

- 2 MW / 0.5 MWh with 2 DC outputs in a 20 feet container *(1MW-15min 1260V on each DC output)*
- NCA / NMC blend Lithium Ion modules

New Hardware architecture:

- High voltage DC output 1500Vdc to decrease energy losses
- New electronic boards and electrotechnical components for battery module management
- Power & Control room and ESS room separated for higher energy density

New Communication architecture:

- New Central unit with optimized and merged functionalities for battery control/command

Remote access and data collection

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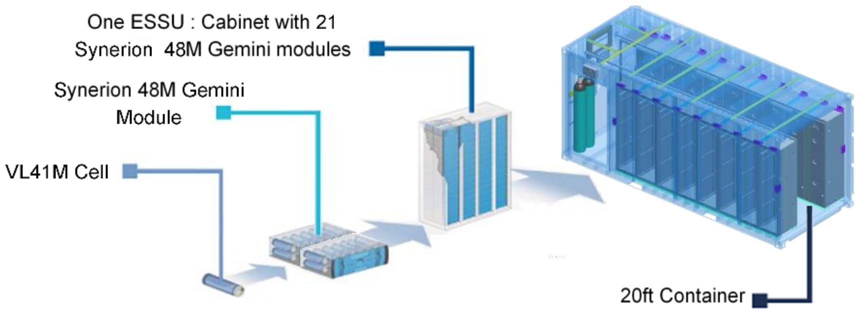

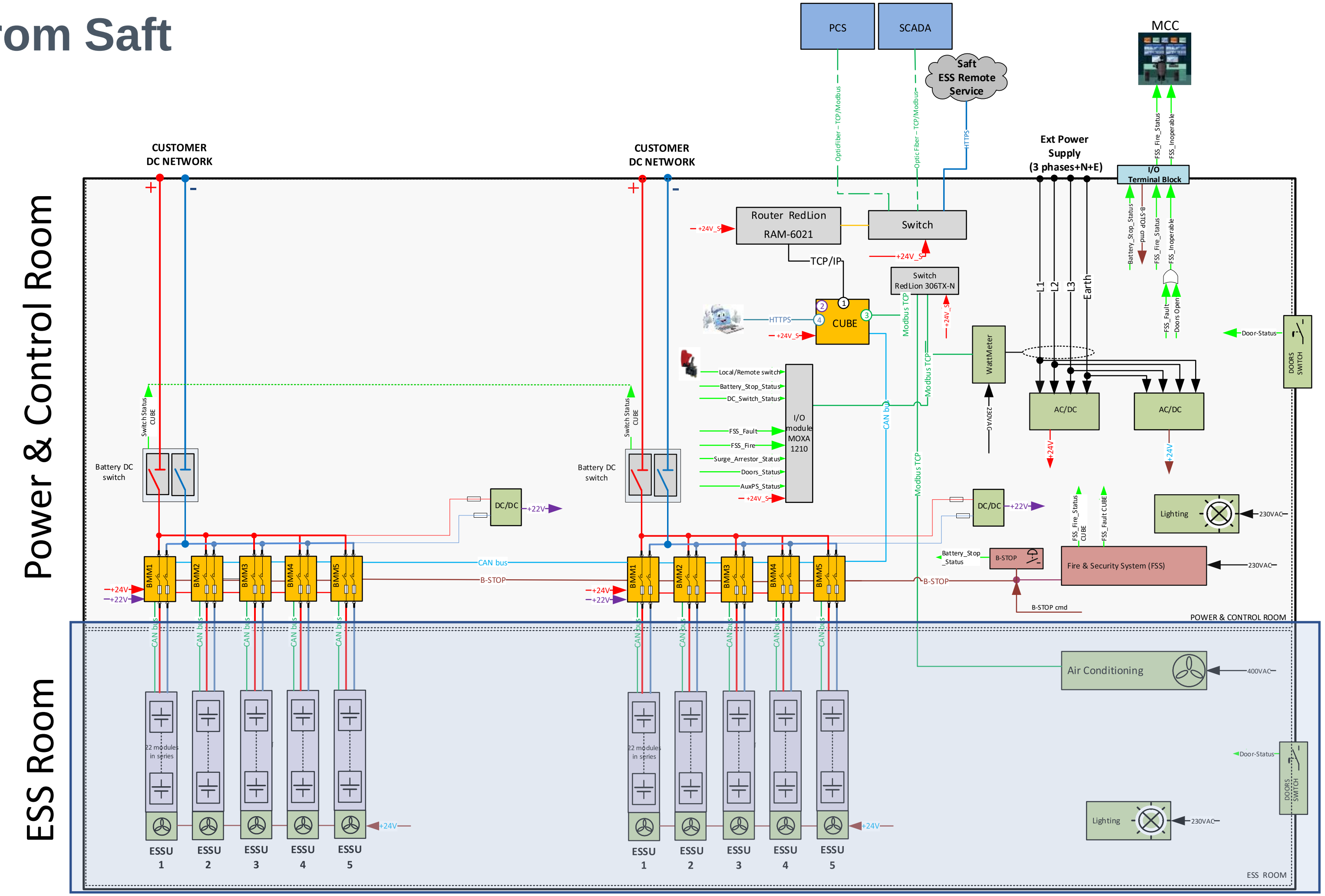

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High-Voltage Lithium-ion battery from Saft

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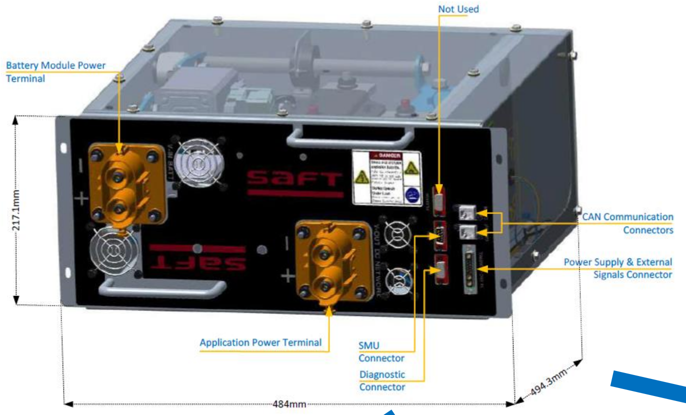
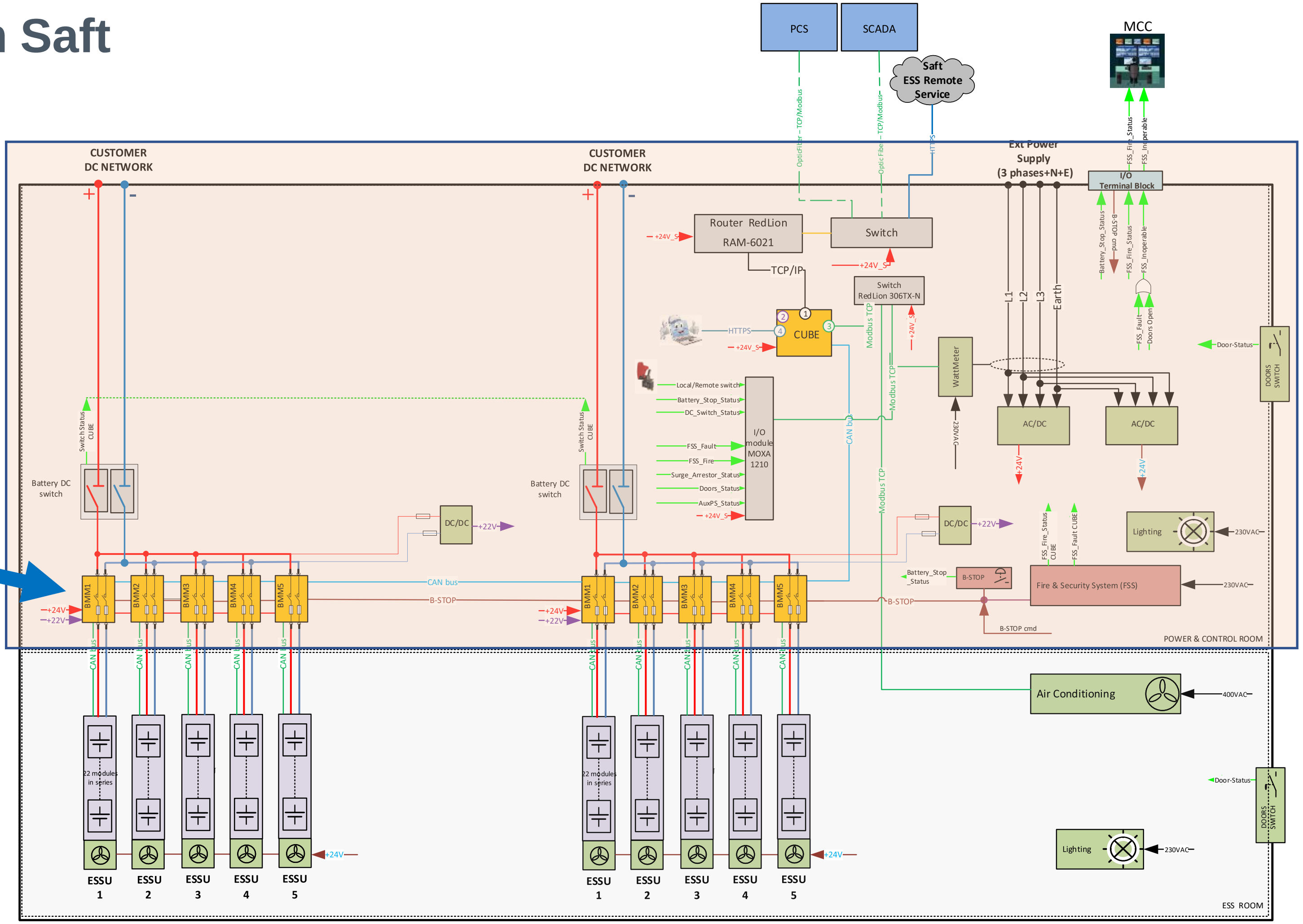


BMM

Battery Management Module

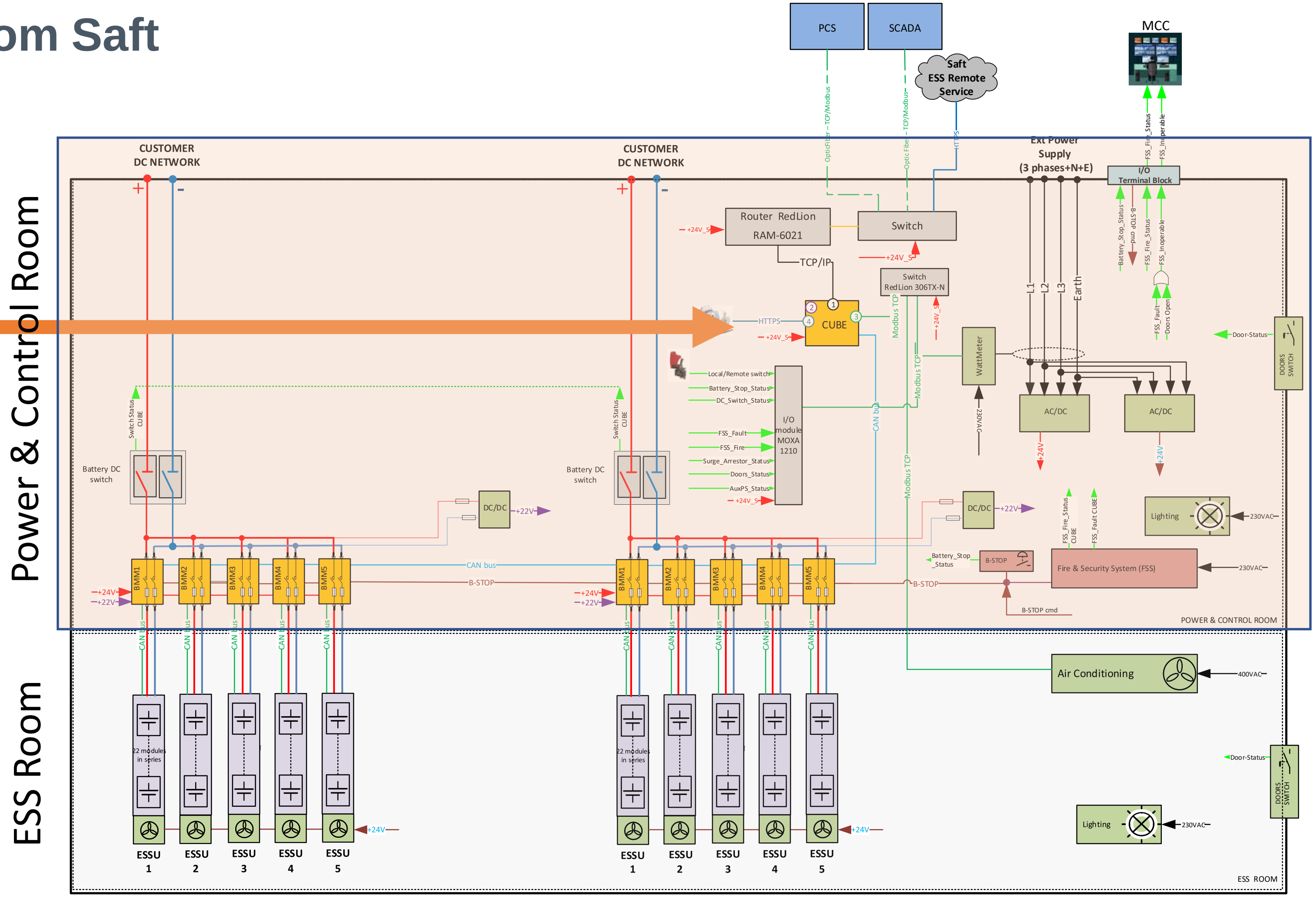
- System management at ESSU level
- Electrical connection/disconection
- Communication with modules for monitoring (cell voltage, T°, etc.)
- Functions calculation (SOC, current limits, etc.)



Hybrid Flexibility Device

High-Voltage Lithium-ion battery from Saft

- New Communication architecture



CUBE

Control Unit for Battery ESS

- Battery Management as central unit
- Aggregation of all battery data
- Computation of battery limits (SOC, voltage, current)
- Collect all status, alarms, warnings

Hybrid Flexibility Device

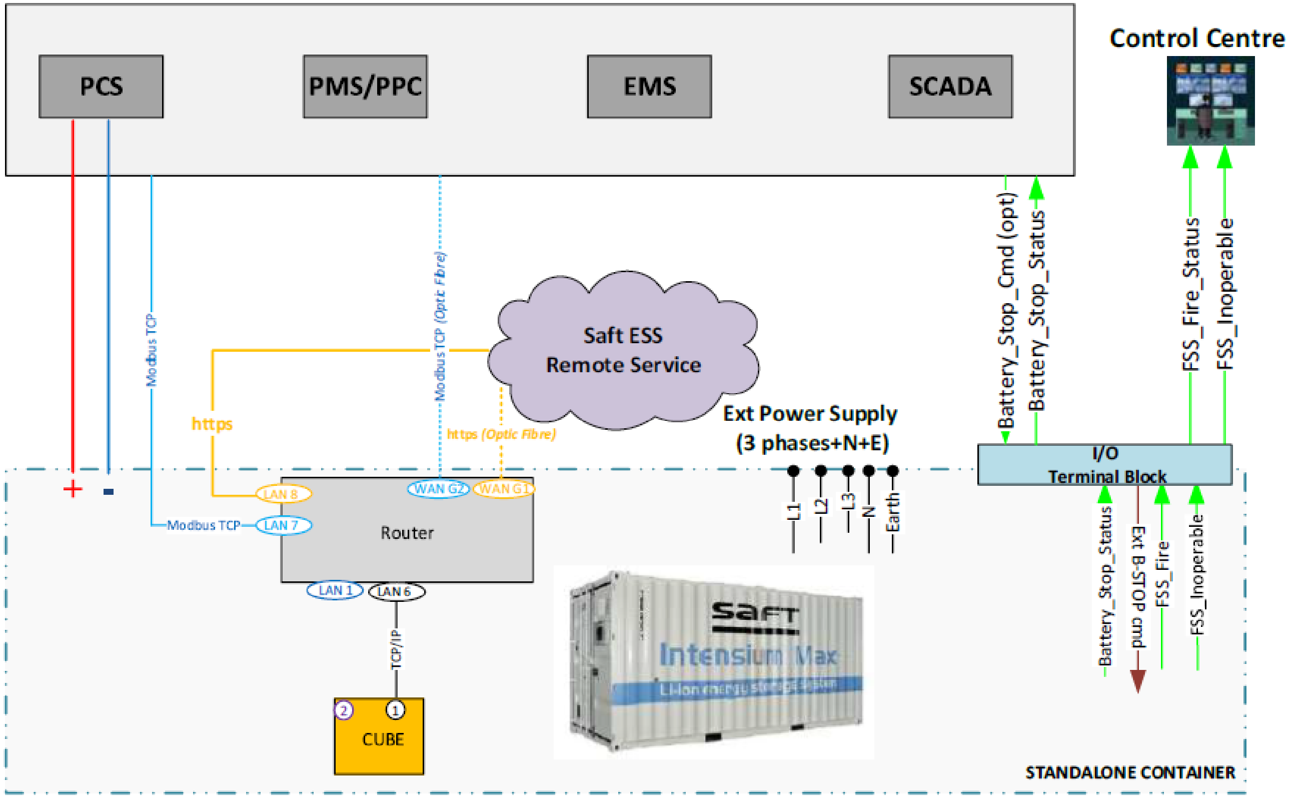
High-Voltage Lithium-ion battery from Saft

- New Communication architecture

CUBE

Control Unit for Battery ESS

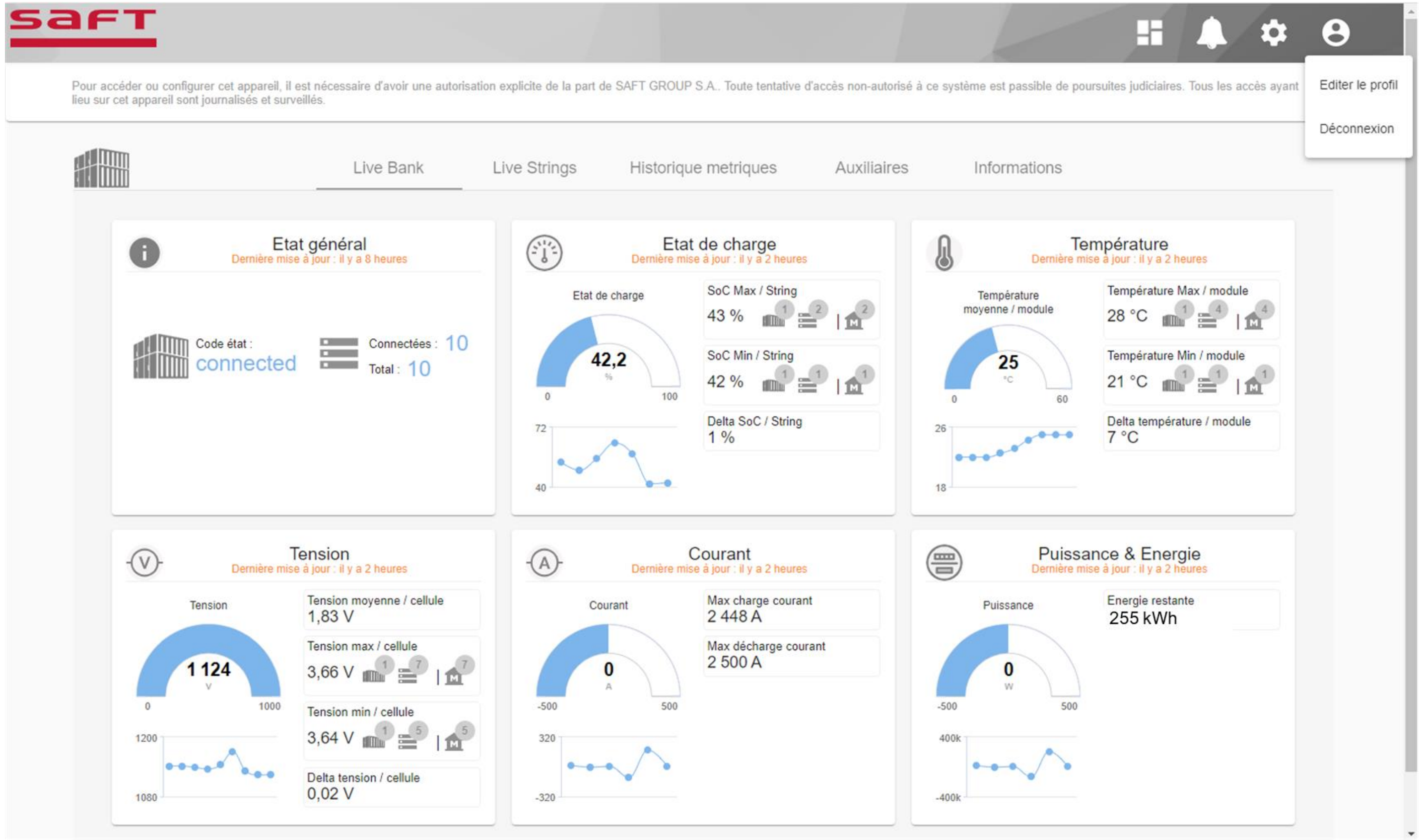
- Interface with PCS, PMS, EMS, SCADA, etc. for control / command
- Manage different battery configurations with parallelization of multiple battery containers
- Allows the control of the system for local maintenance and provides remote services



Hybrid Flexibility Device

High-Voltage Lithium-ion battery from Saft

- Remote access from CLOUD-CUBE (hosted on Microsoft Azure)

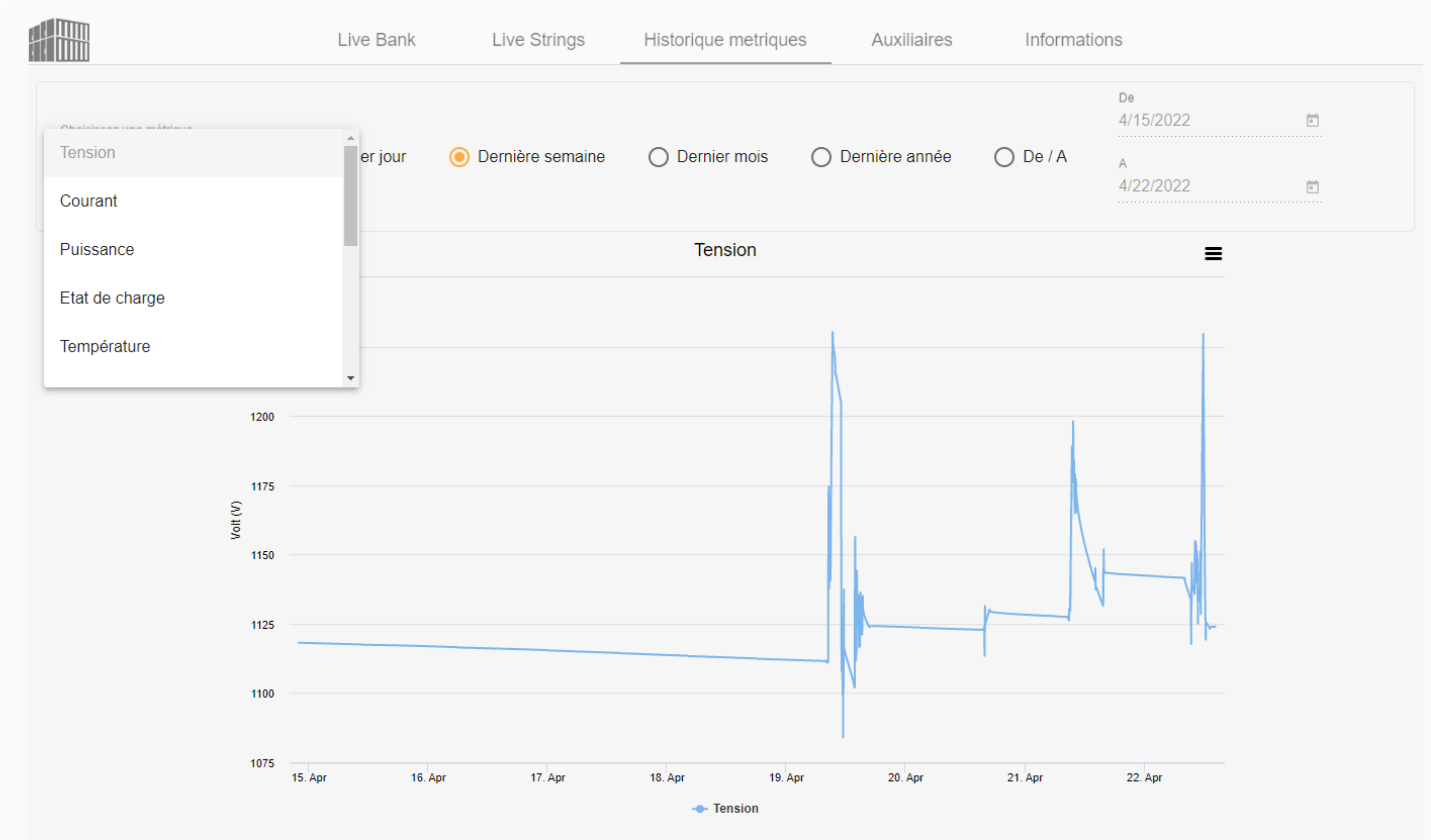


- View of the battery system at container level
  - *SOC, T°, Voltage, Current, Power & Energy*
  - *Historical data of battery*
- View of each string of the battery system
  - *Communication status, Connected / Disconnected, Min and Max Cell Voltage, Current limits, SOC*
- View of the auxiliaries at container level
  - *Power supply status, Auxiliaries consumption (Active and Reactive Power), Fire Suppression System and HVAC status, etc.*

Hybrid Flexibility Device

High-Voltage Lithium-ion battery from Saft

- Remote access from CLOUD-CUBE



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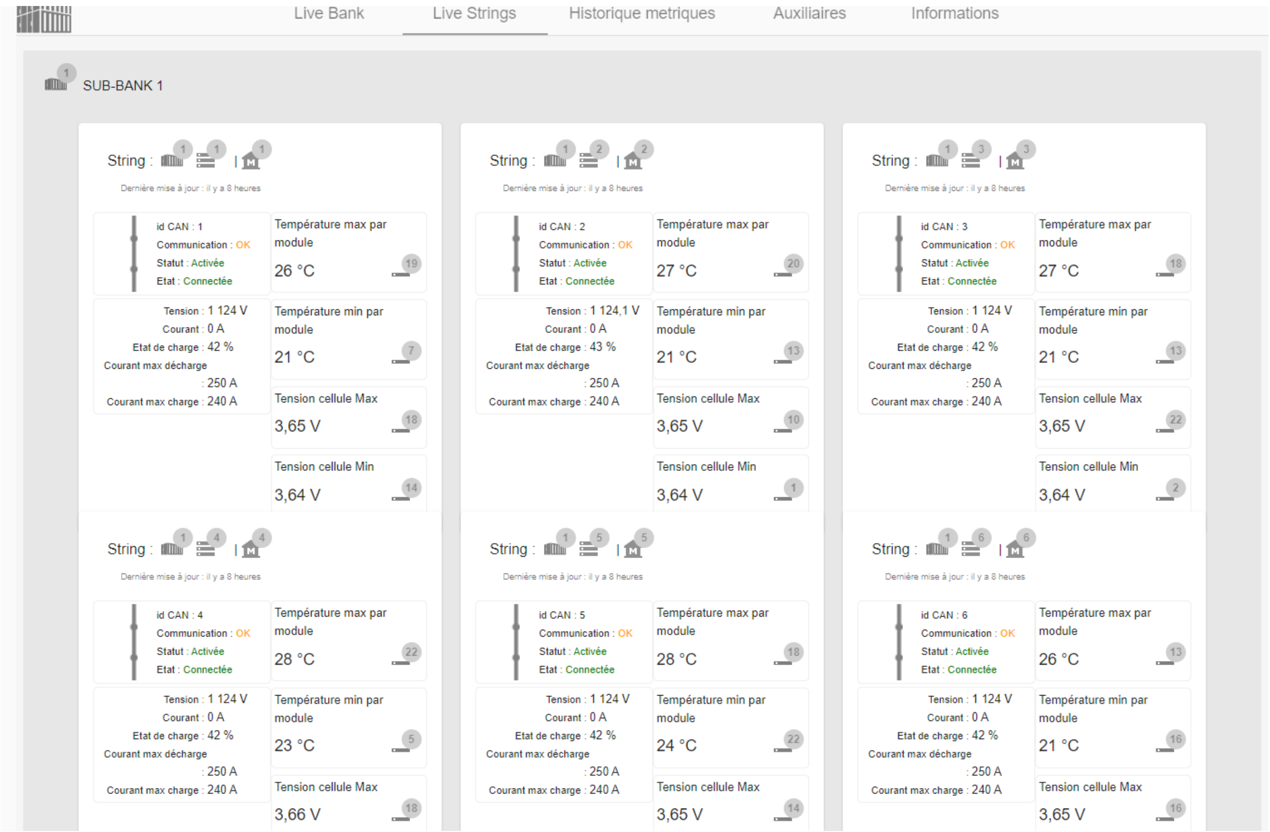

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Hybrid Flexibility Device

High-Voltage Lithium-ion battery from Saft

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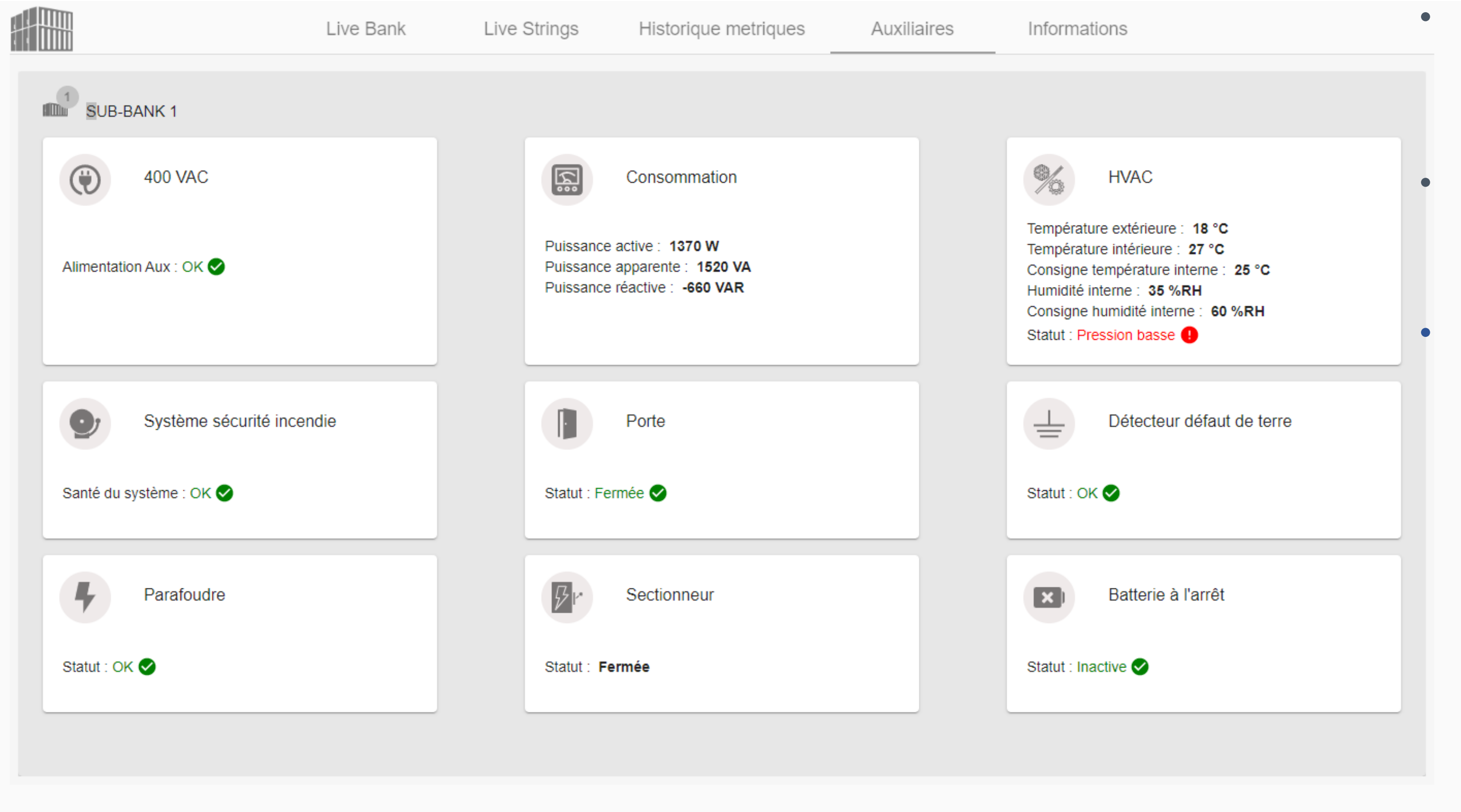

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Hybrid Flexibility Device

High-Voltage Lithium-ion battery from Saft

- Derived features from Osmose demonstrator to Intensium® Max 20 High Energy 1500V (IHE)

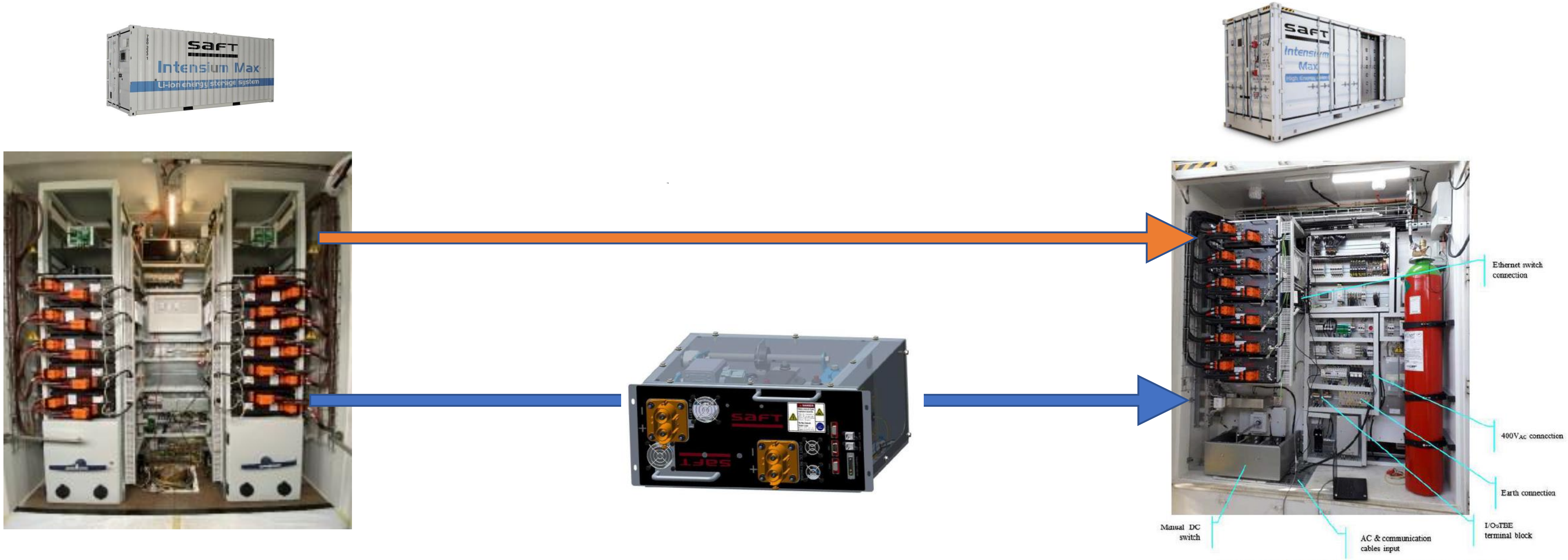


Figure 18 : Electrical cabinet connection points

Hybrid Flexibility Device

High-Voltage Lithium-ion battery:

Container

Li-ion racks and control boards

Power & control room and BMS

New product developed and certified

Main features and innovations:

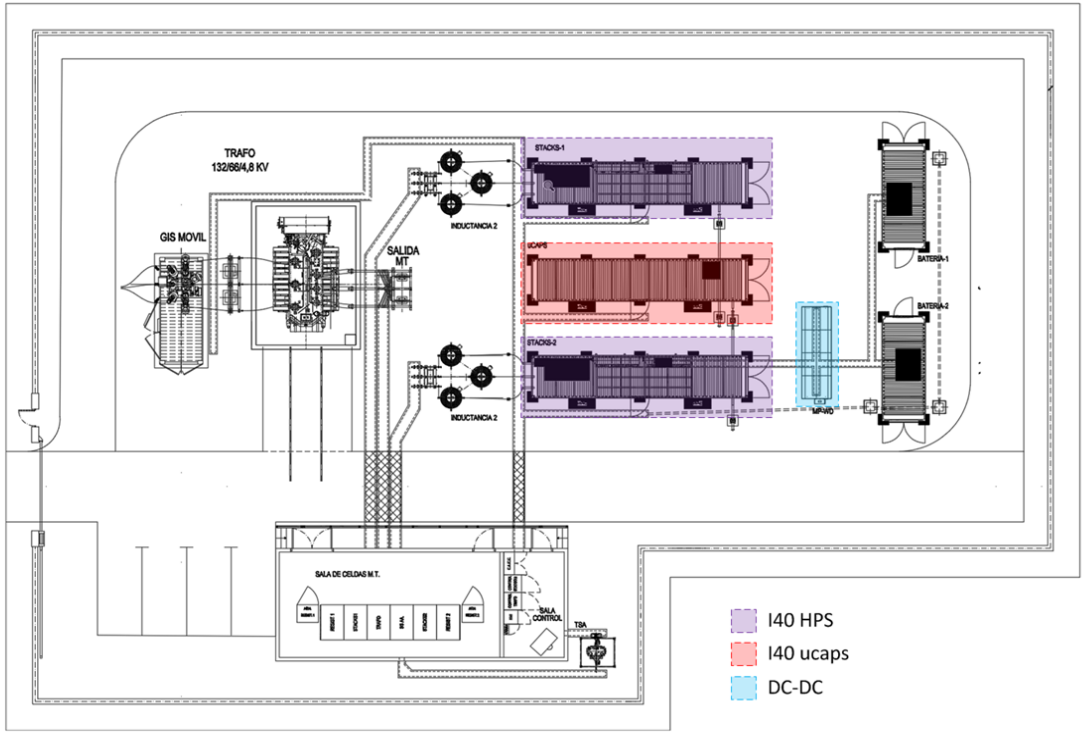
- 2 MW / 0.5 MWh
- 20 feet container
- Nickel-cobalt-aluminium technology
- High voltage battery design (1260 Vdc output) to decrease energy losses
- New electronic boards and battery management module adapted to 1500 Vdc voltage output
- Control and ESS room separated
- New Control unit for battery: new architecture and functionalities (parallelization, iot and cloud services…)
- Remote control

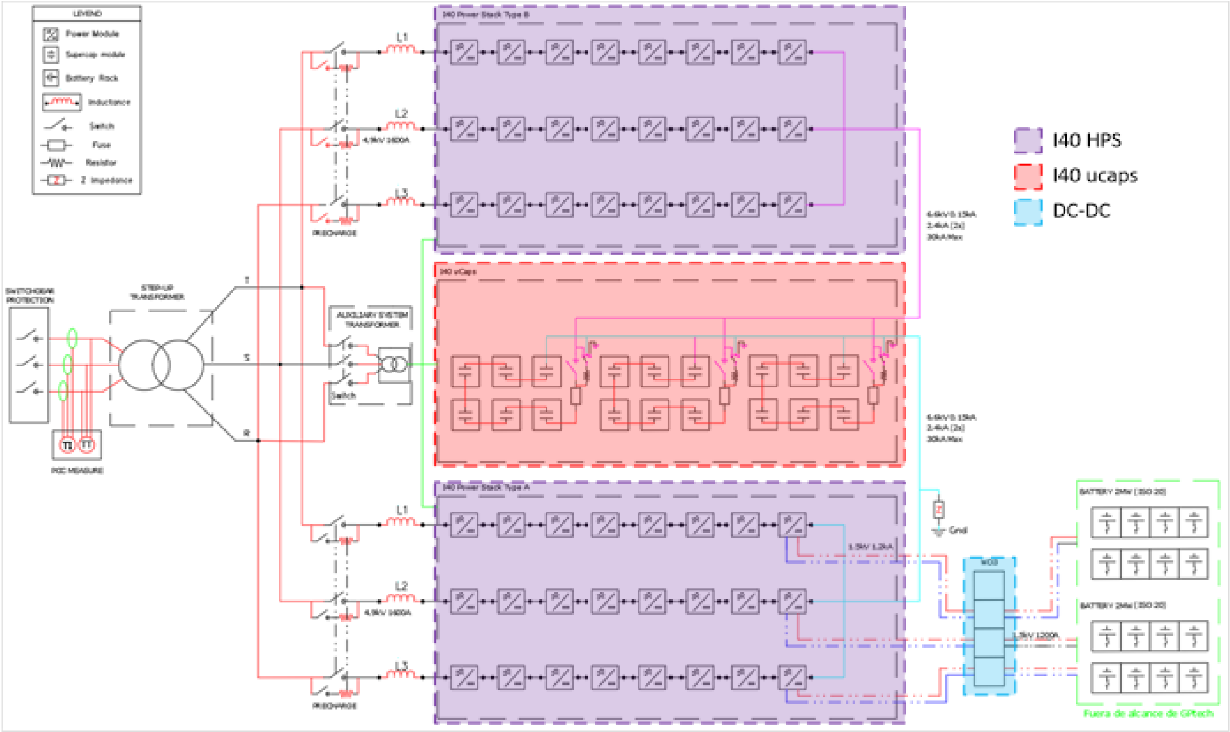
Hybrid Flexibility Device

STATCOM & Supercapacitors container

- Novel Control System + Modularity and versatility in a short time period

In June 2019...



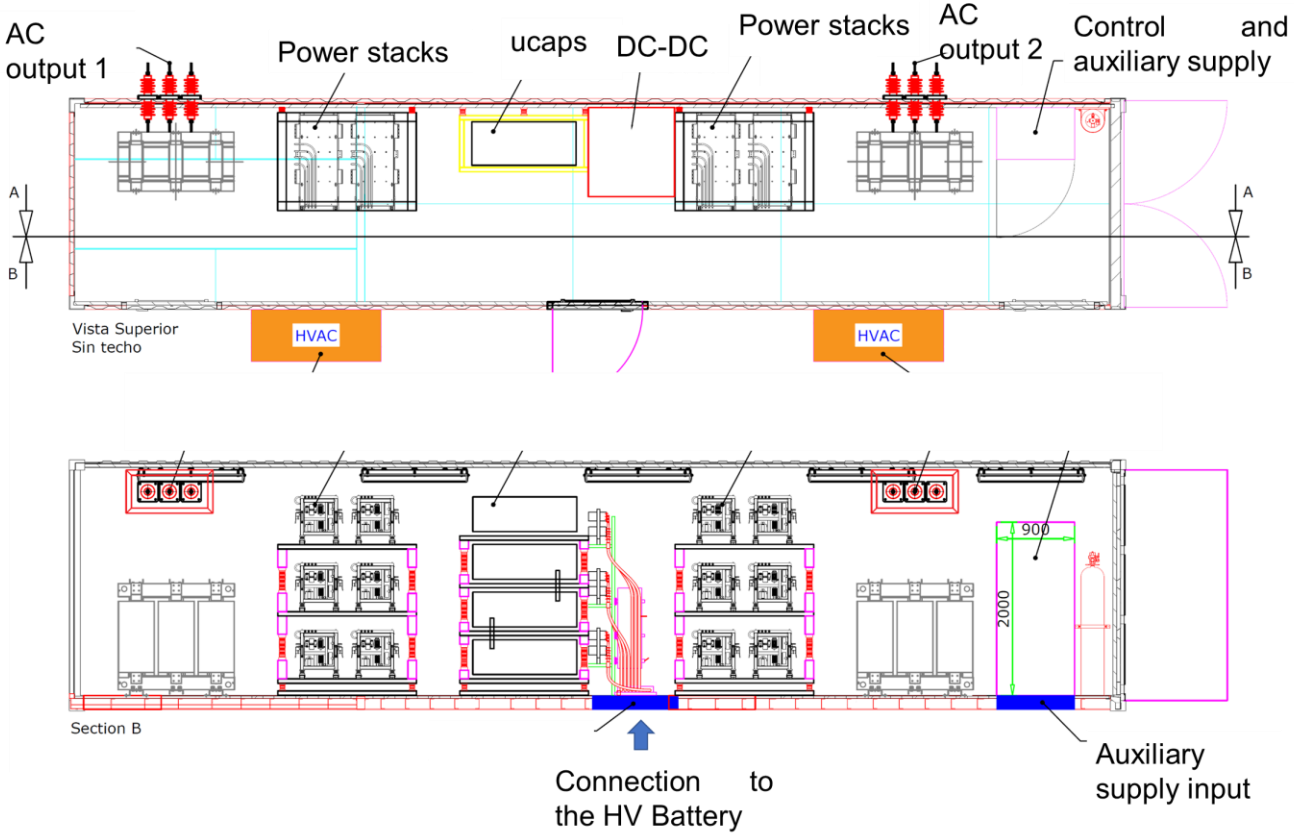


Hybrid Flexibility Device

STATCOM & Supercapacitors container

- Novel Control System + Modularity and versatility in a short time period

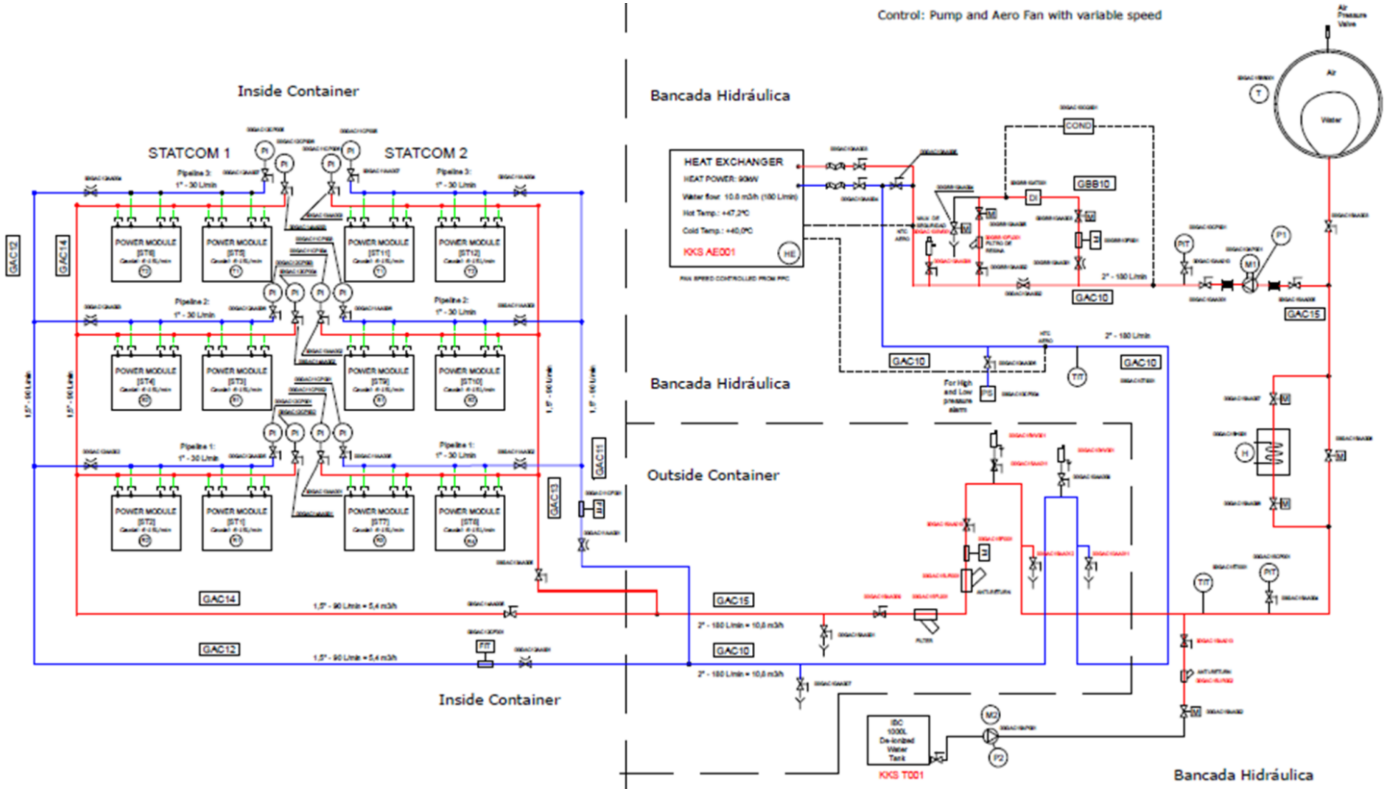
  ...June 2021 and a pandemic situation



Hybrid Flexibility Device

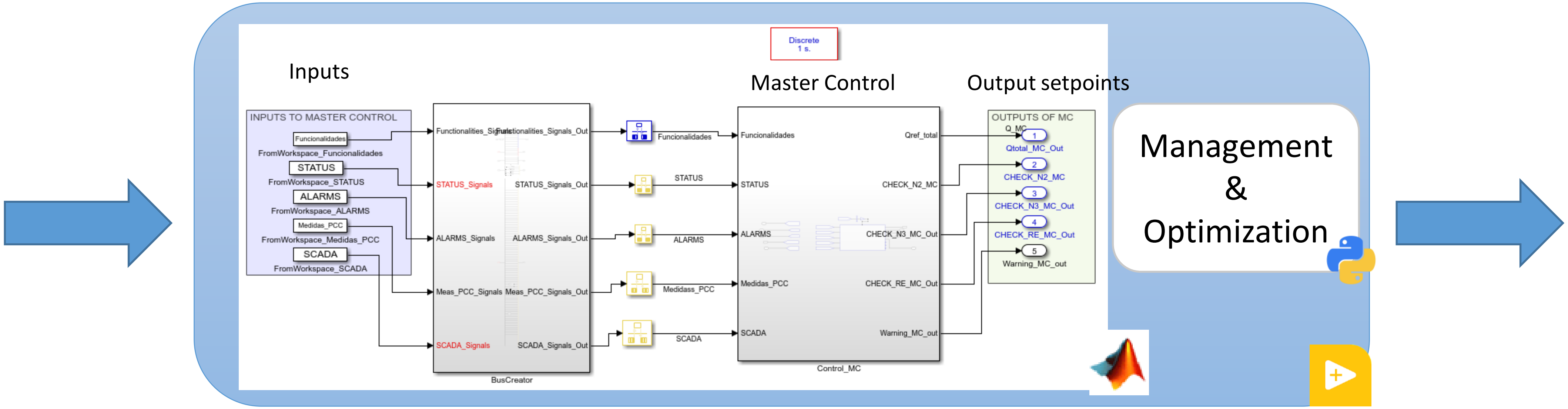
STATCOM & Supercapacitors container

- WITH LIQUID COOLING AS ONE OF THE MAJOR CHALLENGE



Master Control

- The master Control coordinates the optimal operation of different flexibility solutions that constitute the Hybrid Flexibility Device and other existing flexibility devices
- The operator can configure and activate the different flexibility services
- The Master Control determines the setpoints of the devices to provide the required flexibility services



Master Control

- Functionalities by control level and managed by the Master Control:

	1st LEVEL	2nd LEVEL	3rd LEVEL
Objective of the control	Grid stability	Voltage and frequency control	Optimize the management of the flexibility devices
Functionalities	• Inertia emulation • Fast Fault Current Injection • Power Oscillation Damping (POD) • Primary power-frequency regulation	• Continuous power-frequency regulation • Voltage control • Q setpoint control	• Setpoint tracking • Program management • Congestion management

Local control in the HFD
(fast response)

Managed by the Master Control

- Priority, simultaneous activation and power/energy allocations for critical services are defined for the effective coordination of services to provide the grid requirements

Master Control

The Master Control manages the provision of the required grid services while optimize the aging of the devices

Objective optimization function:

$$min\left(\sum_{bat=1}^{n}(Kb_{bat}\cdot S_{bat}+Ksoc_{bat}\cdot|VarSOC_{bat}|+Kp_{bat}\cdot|VarP_{bat}|)+K_{pns}\cdot|pns|\right)$$

unnecessary use of equipment

State-of-charge deviation

operation in aggressive power ranges and/or far from minimize degradation ranges

not served energy

Optimization constraints:

- State-of-charge limits, electrical and capacity boundaries of each equipment
- Active power and energy allocated for level functionalities
- TSO set-point requirement fulfilment

A. Kalms, F. Bouchotrouch, P. Pernaut, M. Estévez, “Multi Services Provided by the Coordination Control of Different Storage and FACTS Devices,” in *11th Solar & Storage Integration Workshop, Berlin, Germany, 2021.*

Master Control

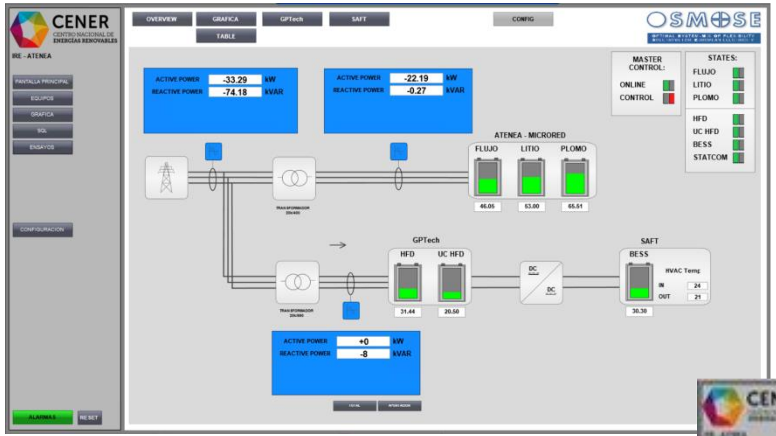
Master Control user-interface for configuration and operation of the demonstrator

General interface of the Master Control

Interface for functionalities selection in the Master Control

SCADA

A dedicated SCADA has been developed for monitoring and visualization of demonstrator elements and operational variables



Demonstrator schematic in the SCADA

Results visualization in the SCADA

Hybrid Flexibility Device interface in the SCADA

Real-operation results

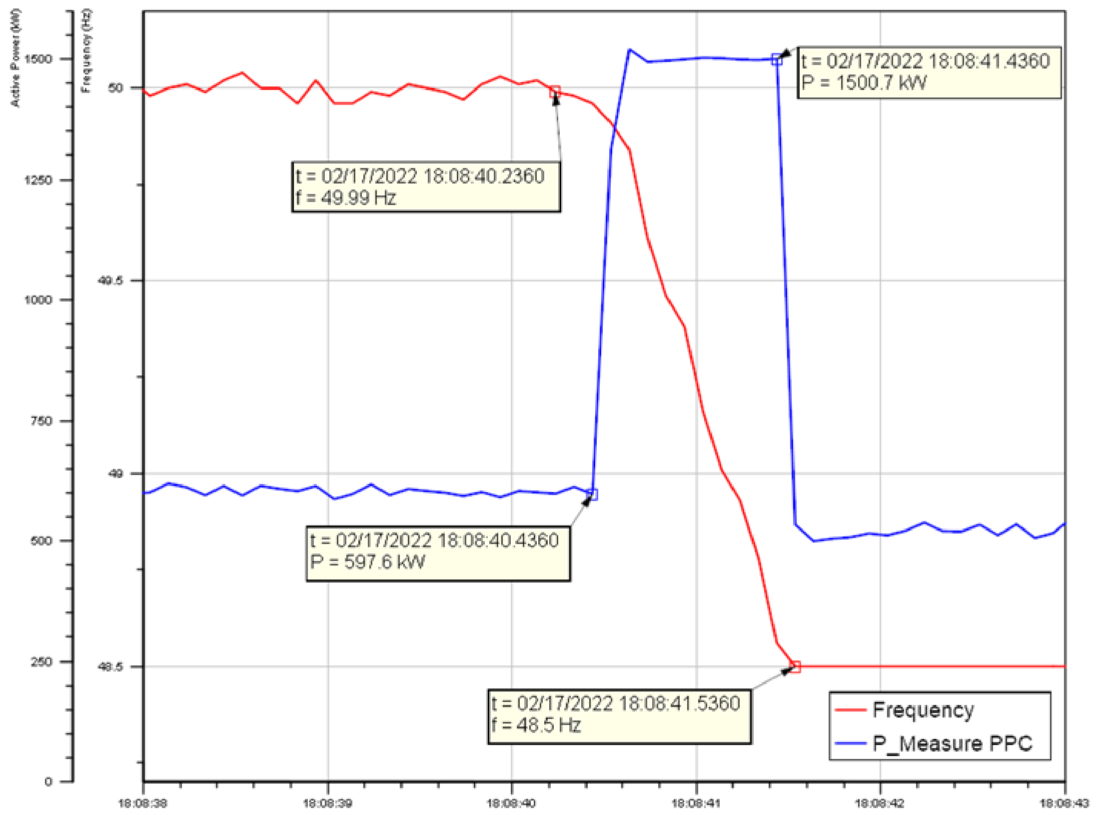
Level 1 Functionalities:

- **Inertia emulation. Proportional to the frequency derivative (INE)**
- Fast Frequency Response (FFR-0 & FFR-1)
- P-f Regulation (PFR-p)
- Fast Reactive Current injection (FRC-0 & FRC-1)
- Trapezoidal Response (TRP)

Real-operation results

Level 1 Functionalities:

Inertia emulation. Proportional to the frequency derivative (INE)



$$\Delta P = 2 * H * \frac{df}{dt}$$

*2*H gain represents the inertia to be emulated. Its values range from 1 to 20.*

	df/dt	P_HFD_pretest	P_HFD_final	ΔP_HFD	Deviation (%)	Acceptance
INE-0 (a)	- 2 Hz/s	P_{HFD} = 600 kW	P_{HFD} = 600 kW	0 kW	0 %	✓
INE-0 (b)	2 Hz/s	P_{HFD} = 600 kW	P_{HFD} = 600 kW	0 kW	0 %	✓
INE-1 (a)	- 0.4 Hz/s	P_{HFD} = 600 kW	P_{HFD} = 600 kW	0 kW	0 %	✓
INE-1 (b)	- 1.5 Hz/s	P_{HFD} = 600 kW	P_{HFD} = 766.4 kW	166.4 kW	0.95 %	✓
INE-1 (c)	- 1.5 Hz/s	P_{HFD} = 600 kW	P_{HFD} = 1500.7 kW	900.7 kW *	*	✓
INE-1 (d)	- 1.5 Hz/s	P_{HFD} = 600 kW	P_{HFD} = 1512.9 kW	912.9 kW *	*	✓
INE-1 (e)	- 3 Hz/s	P_{HFD} = 600 kW	P_{HFD} = 927.9 kW	327.9 kW	2.41 %	✓
INE-1 (f)	- 3 Hz/s	P_{HFD} = 600 kW	P_{HFD} = 1503.7 kW	903.7 kW *	*	✓
INE-1 (g)	- 3 Hz/s	P_{HFD} = 600 kW	P_{HFD} = 1500 kW	900 kW *	*	✓
INE-1 (h)	0.4 Hz/s	P_{HFD} = 600 kW	P_{HFD} = 600 kW	0 kW	0 %	✓
INE-1 (i)	1.5 Hz/s	P_{HFD} = 600 kW	P_{HFD} = 437.4 kW	- 162.6 kW	3.21 %	✓
INE-1 (j)	1.5 Hz/s	P_{HFD} = 600 kW	P_{HFD} = - 364.5 kW	- 964.5 kW	4.31 %	✓
INE-1 (k)	1.5 Hz/s	P_{HFD} = 600 kW	P_{HFD} = - 832 kW	- 1432 kW	4.54 %	✓
INE-1 (l)	3 Hz/s	P_{HFD} = 600 kW	P_{HFD} = 265.6 kW	- 334.4 kW	0.48 %	✓
INE-1 (m)	3 Hz/s	P_{HFD} = 600 kW	P_{HFD} = - 874 kW	- 1474 kW	1.73 %	✓
INE-1 (n)	3 Hz/s	P_{HFD} = 600 kW	P_{HFD} = - 865 kW	- 1465 kW	2.33 %	✓

Real-operation results

Level 2 Functionalities:

- **Voltage Control based on Reactive Power Setpoint Control (VCQ)**
- Voltage Control based on Voltage Setpoint (VCV)
- **Power-frequency Regulation. Nominal regime (PFR-n)**

Real-operation results

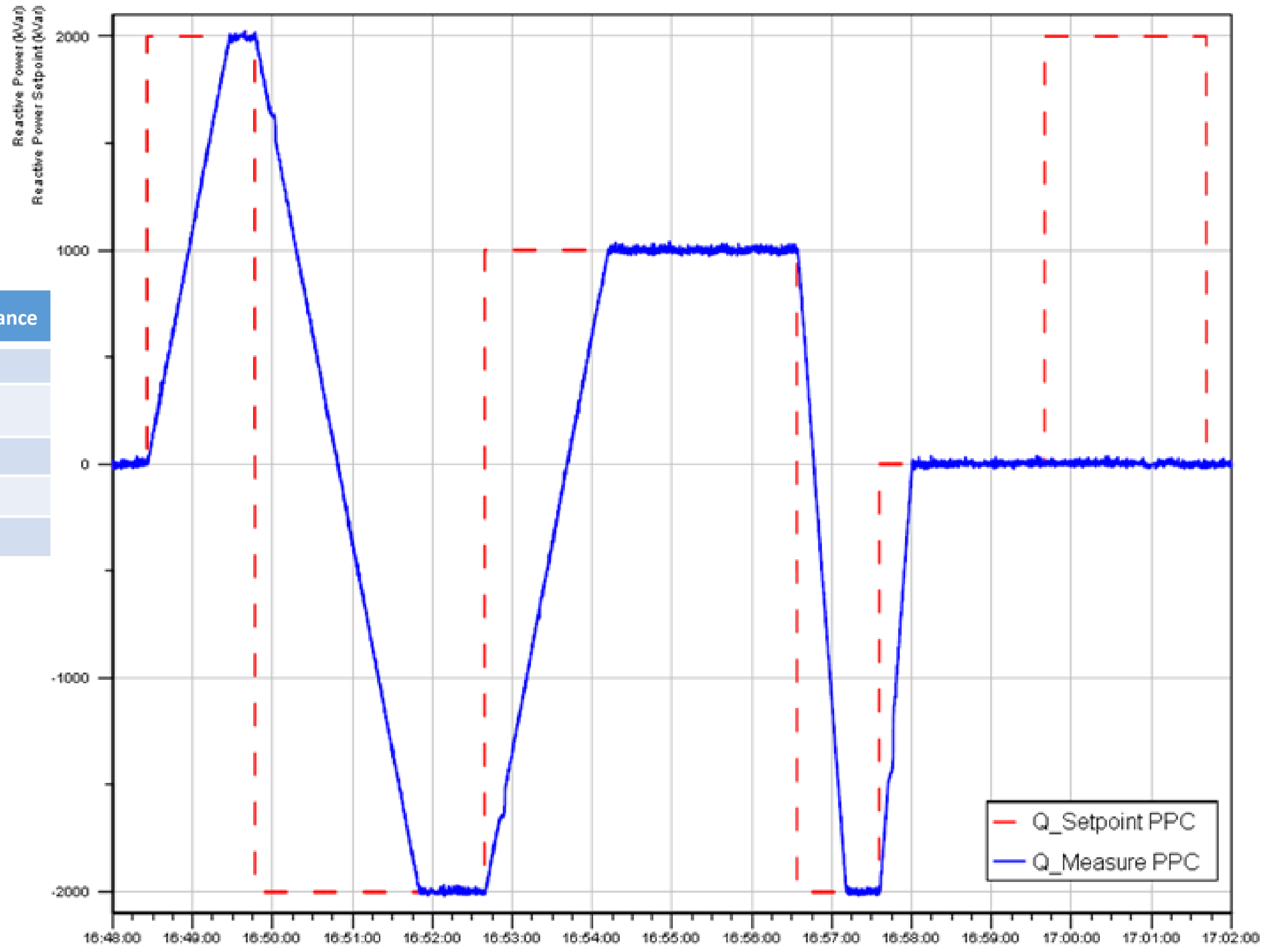
Level 2 Functionalities:

Reactive Power Setpoint Control (VCQ)

- *Parameterizable online ramps up to 20ms*
- *Possibility to disable tracking (VCQ(a))*

	Q_HFD init	Q_HFD final	Init time	Final time	Ramp time	Error	Acceptance
VCQ (b)	3,2 kVAr	1991,4 kVAr	16:48:25.8190	16:49:27.0190	61,2s	2%	✓
VCQ (d)	1982,4 kVAr	-1996,7 kVAr	16:49:47.8190	16:51:49.9190	61,05s	1,75 %	✓
VCQ (c)	-2003,2 kVAr	998,9 kVAr	16:52:39.9190	16:54:12.3190	30,8s	2,6%	✓
VCQ (e)	999,0 kVAr	-1989,7 kVAr	16:56:34.3190	16:57:10,9190	12,2s	1,6%	✓
VCQ (a)	0 kVAr	0 kVAr	-	-	-	-	✓

a) Ramp from 0MVAr to 2MVAr with 2MVAr/min and control disabled VCQ (a))
b) Ramp from 0MVAr to 2MVAr with 2MVAr/min (VCQ (b))
c) Ramp from 2MVAr to -2MVAr with -2MVAr/min (VCQ (d))
d) Ramp from –2MVAr to 1MVAr with 2MVAr/min (VCQ (c))
e) Ramp from 1MVAr to -2MVAr with -5MVAr/min VCQ (e))

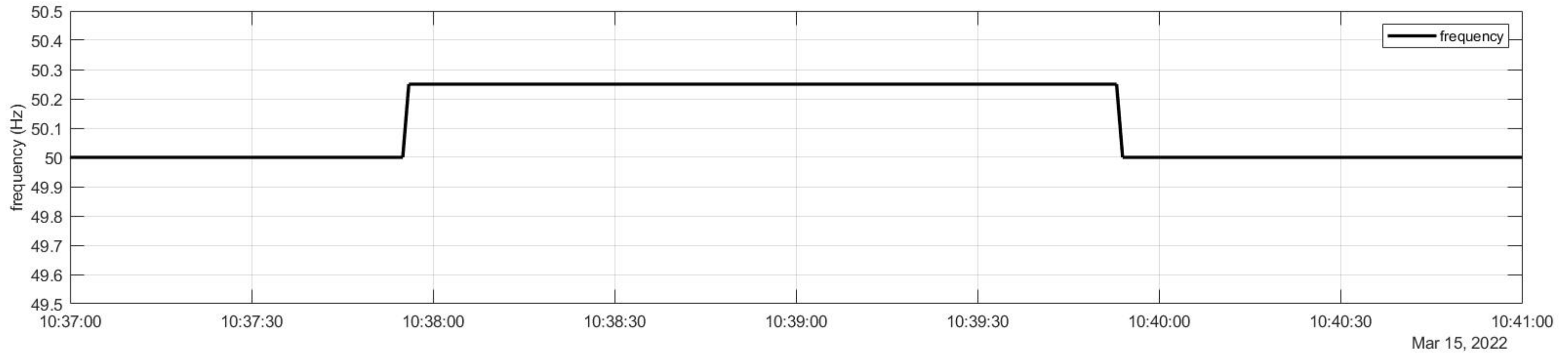


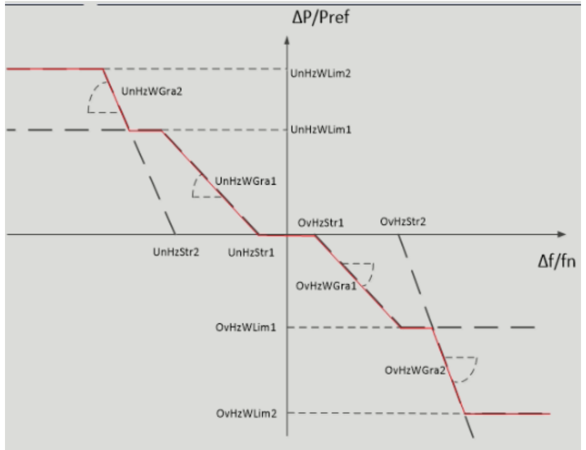
Real-operation results

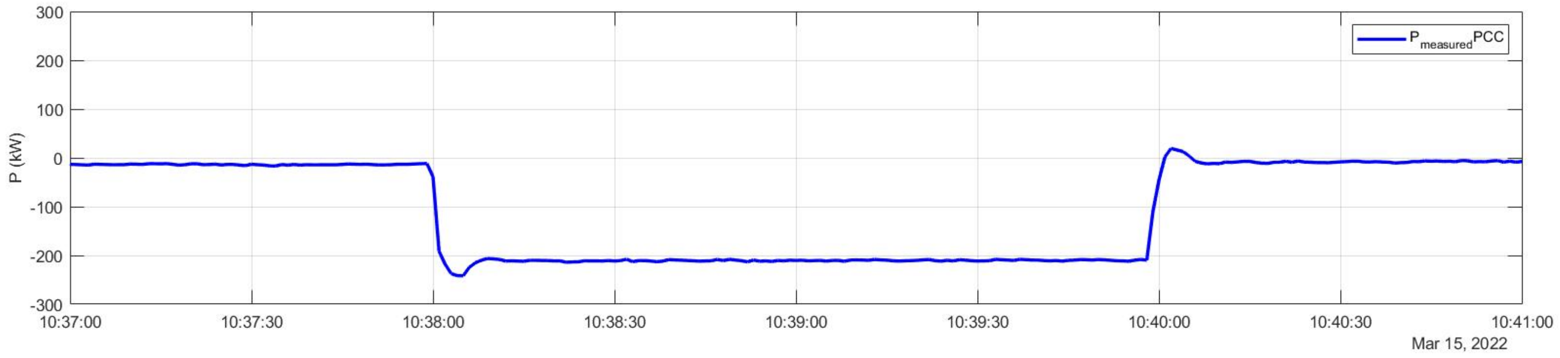
Level 2 Functionalities:

Continuous Power-Frequency Regulation (PFR-n)

Active power absorption at PCC to restore frequency of the grid







Real-operation results

Level 3 Functionalities:

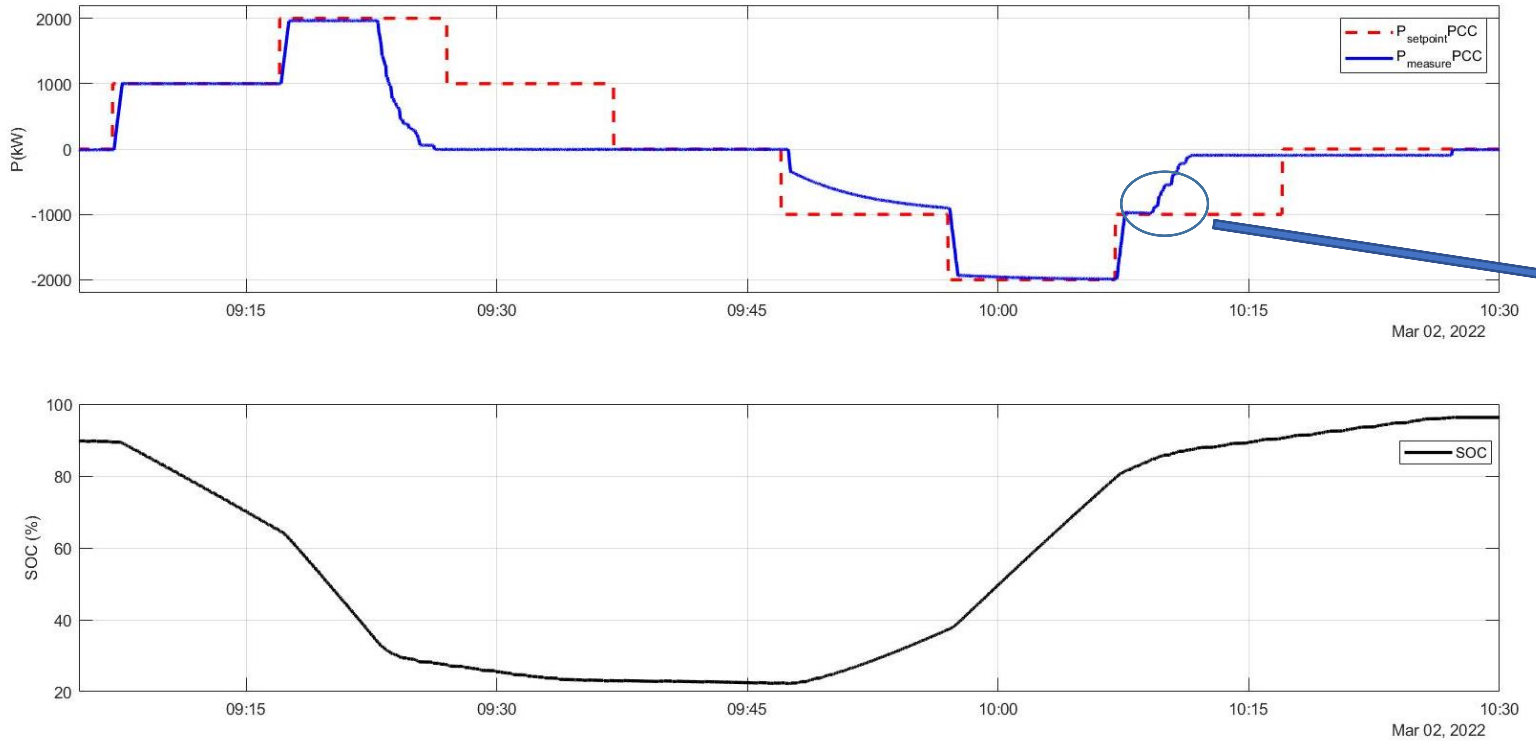
- Setpoint Tracking (SPT)
- **Program Management (PGM)**
- Congestion Management (CMT)

Real-operation results

Level 3 Functionalities:

Program Management (PGM)

Active power program profile execution and SOC limitation



Storage power allocation:

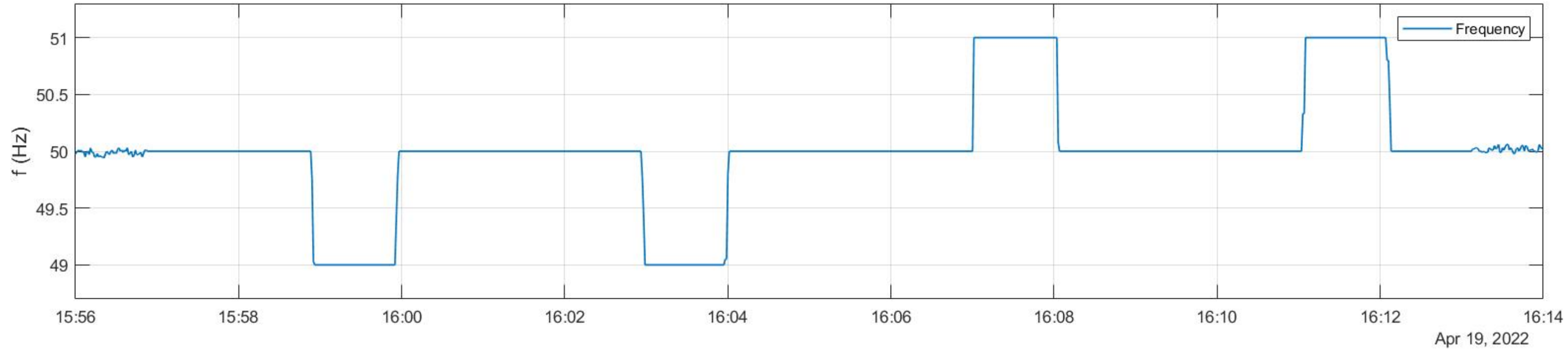
Time	P_{HFD}	P_{Li}	P_{Pb}
10:09:05	-969,16	0	0
10:09:06	-952,77	0	-16
10:09:07	-928,86	-15	-20
10:09:08	-928,86	-15	-20

Real-operation results

Level 1 and 3 Functionalities:

Program Management and Primary Power-Frequency Regulation

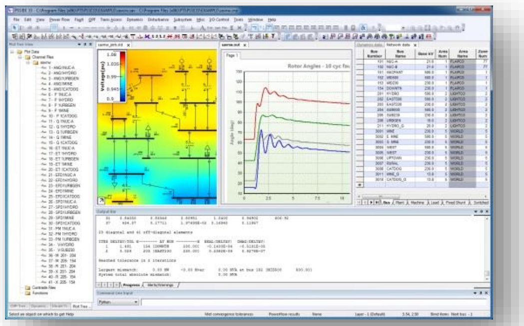
Simultaneous active power program profile execution and frequency deviation

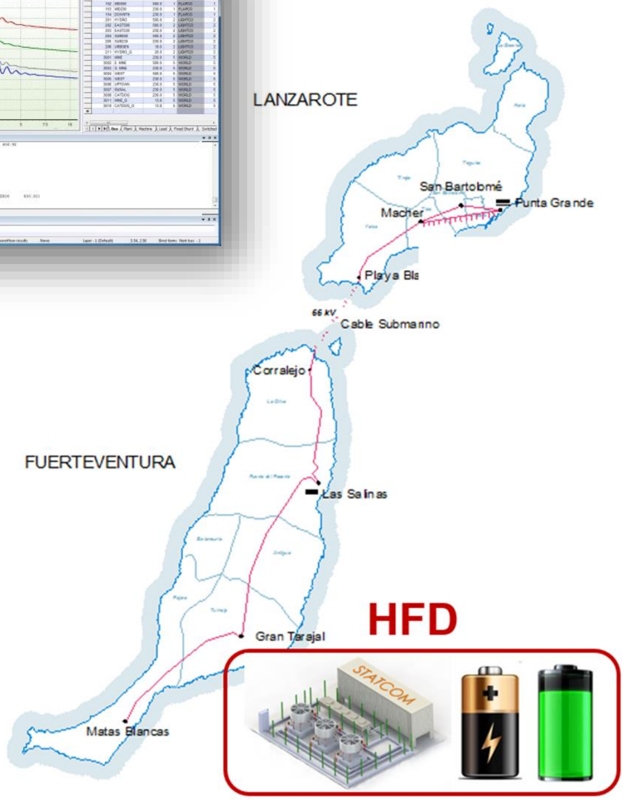


Canary Islands simulation results

Simulations in Lanzarote-Fuerteventura power system

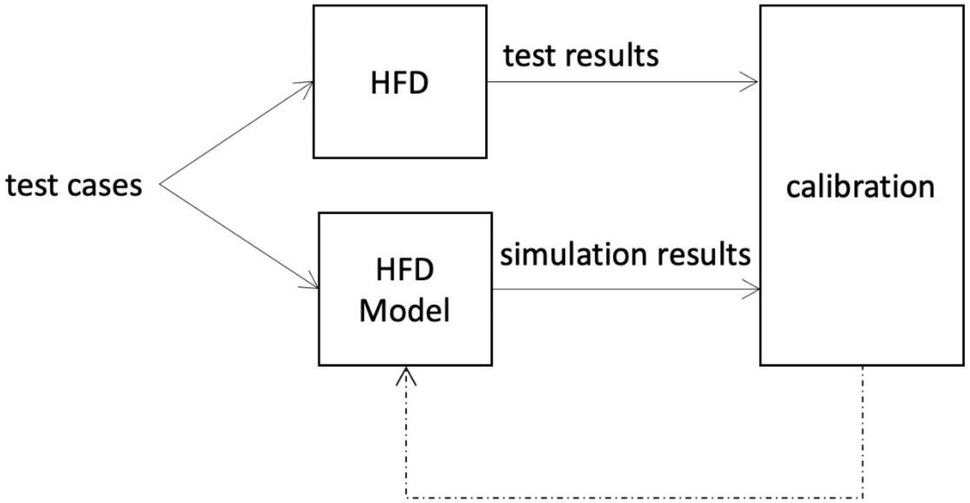
- Validation of functionalities (P, Q, V setpoint change)
- Sensitivity analysis of control parameters and optimal tunning
- Simulation of HFD performance under different scenarios
  - Generation tripping
  - Voltage dip
  - 3-phase fault



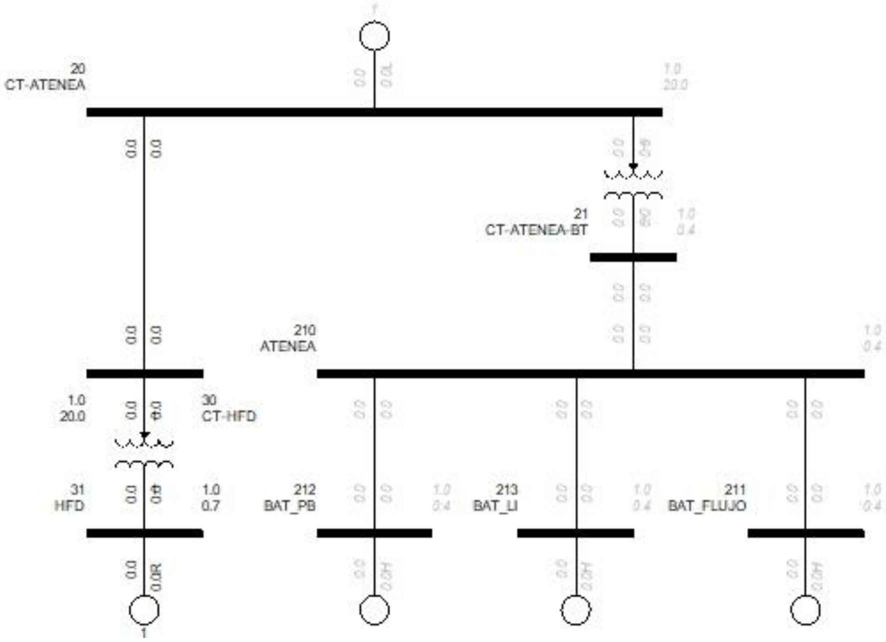


Simulation solution

- **Simulation procedure**

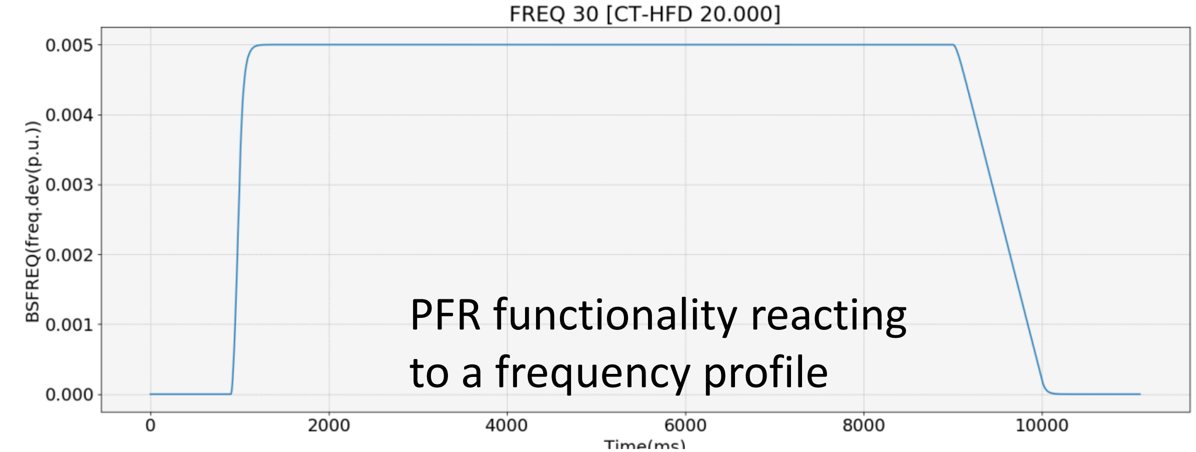


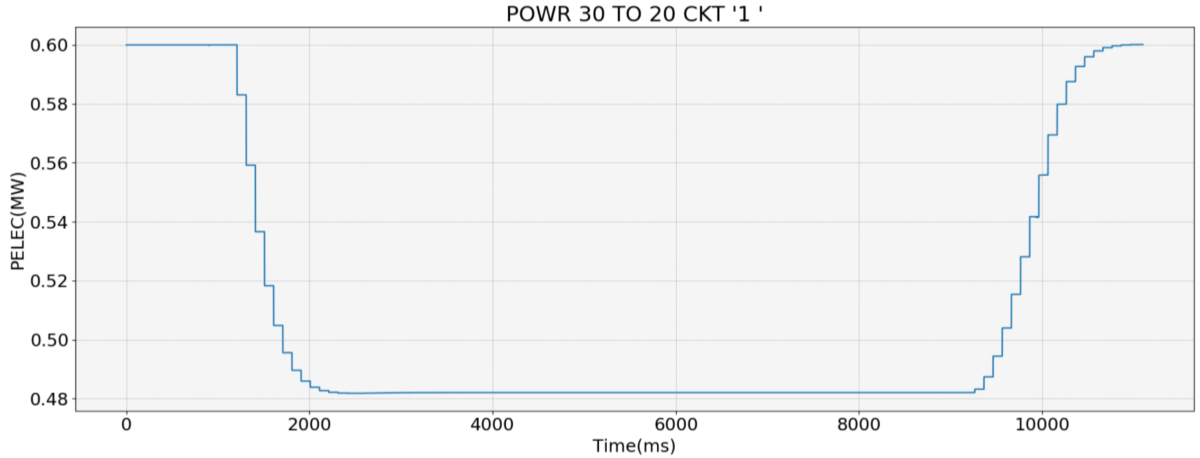
- **Simulation platform:** PSS-E + Python

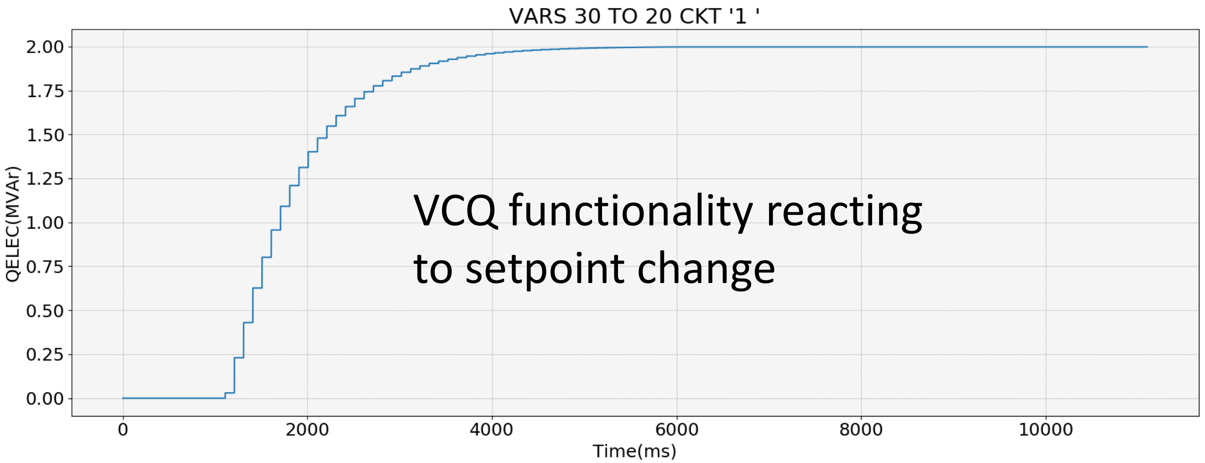


Validation of functionalities

- **Using data series or providing different setpoints.**

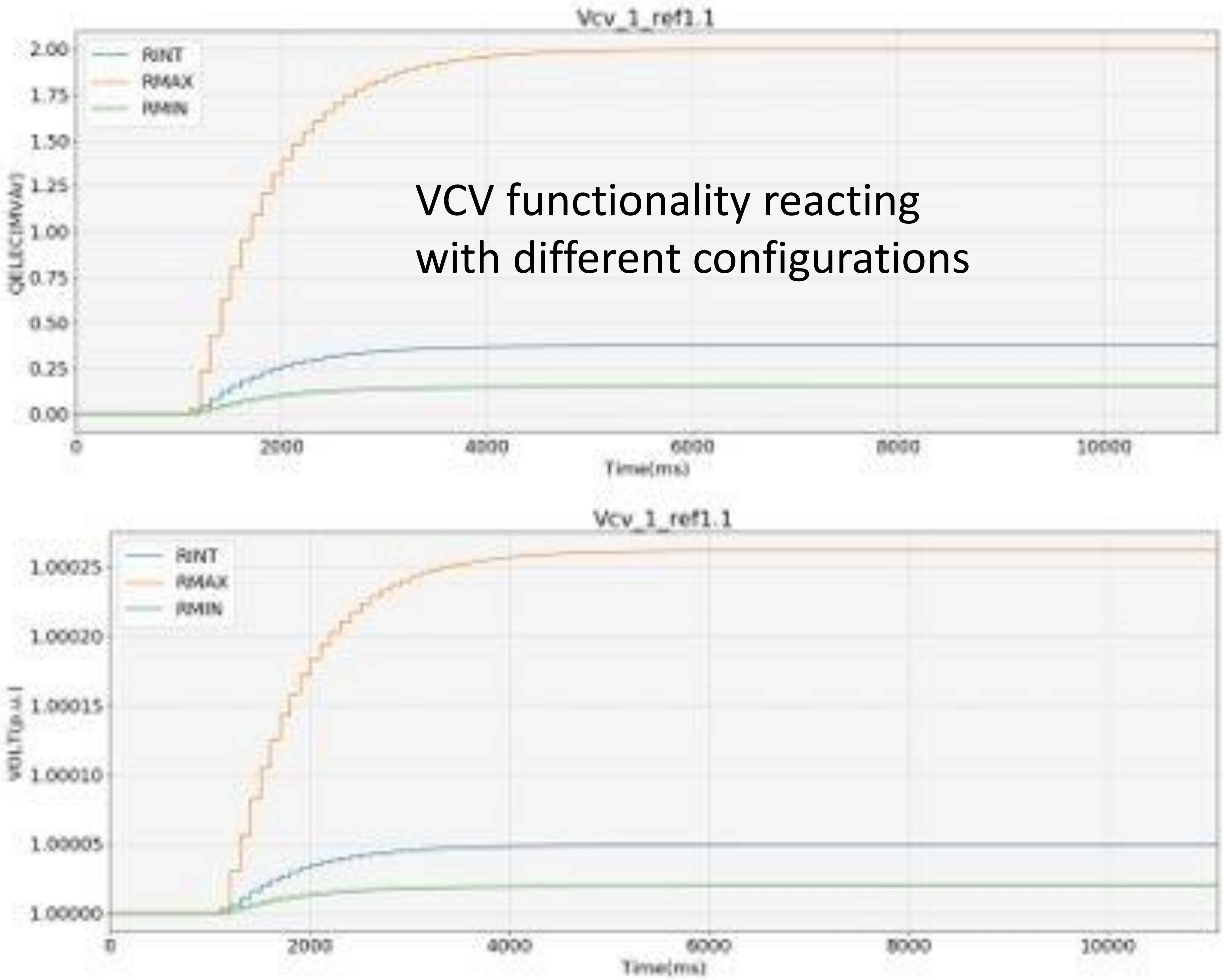






Sensitivity analysis

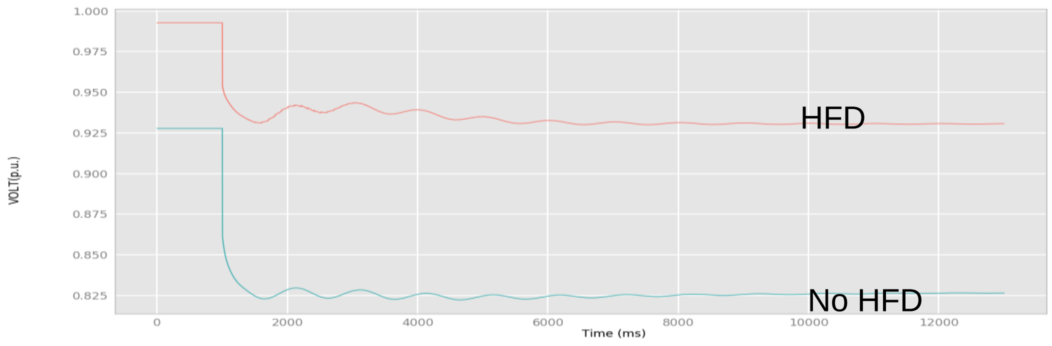
- **Testing several configurations**



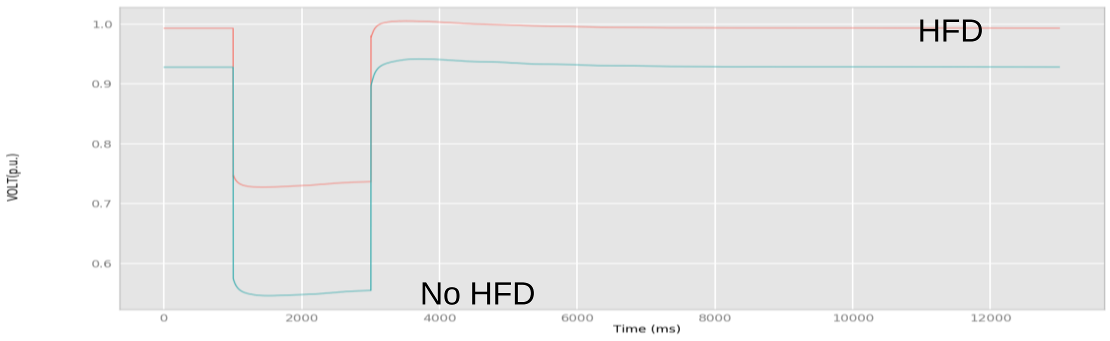
Canary Islands simulation results

Simulations in Lanzarote-Fuerteventura power system shows the positive contribution of the HFD for voltage control, frequency response and fast reactive current injection

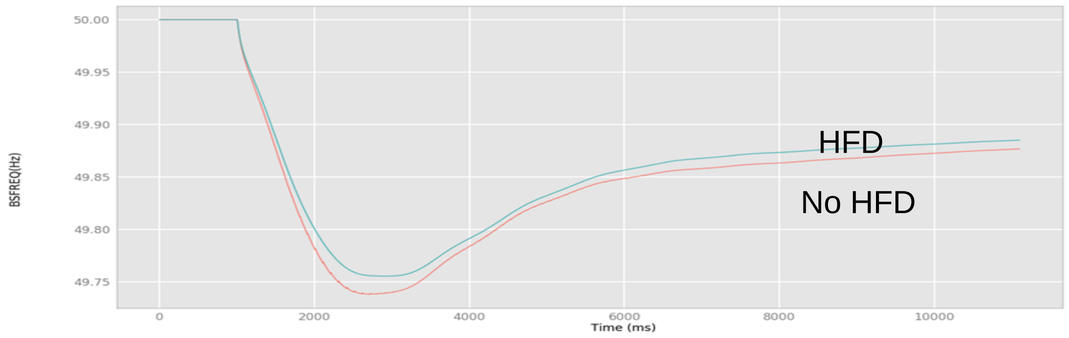
Voltage Control when 3 generators trips



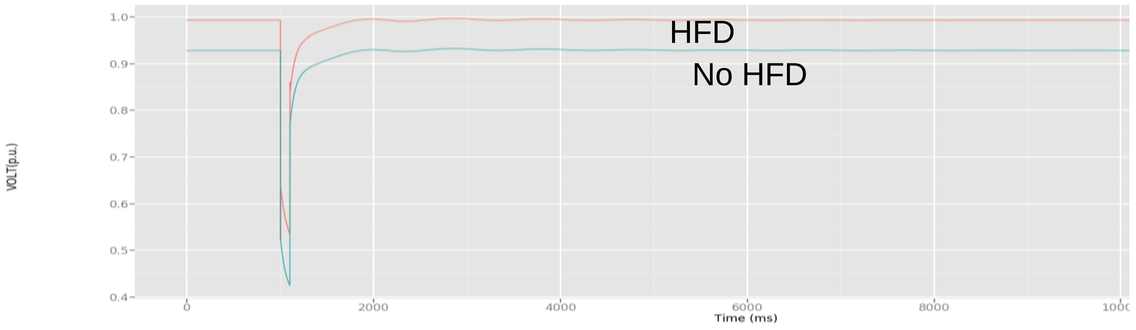
Fast reactive current injection (voltage dip)



Frequency response when 1 generator trips

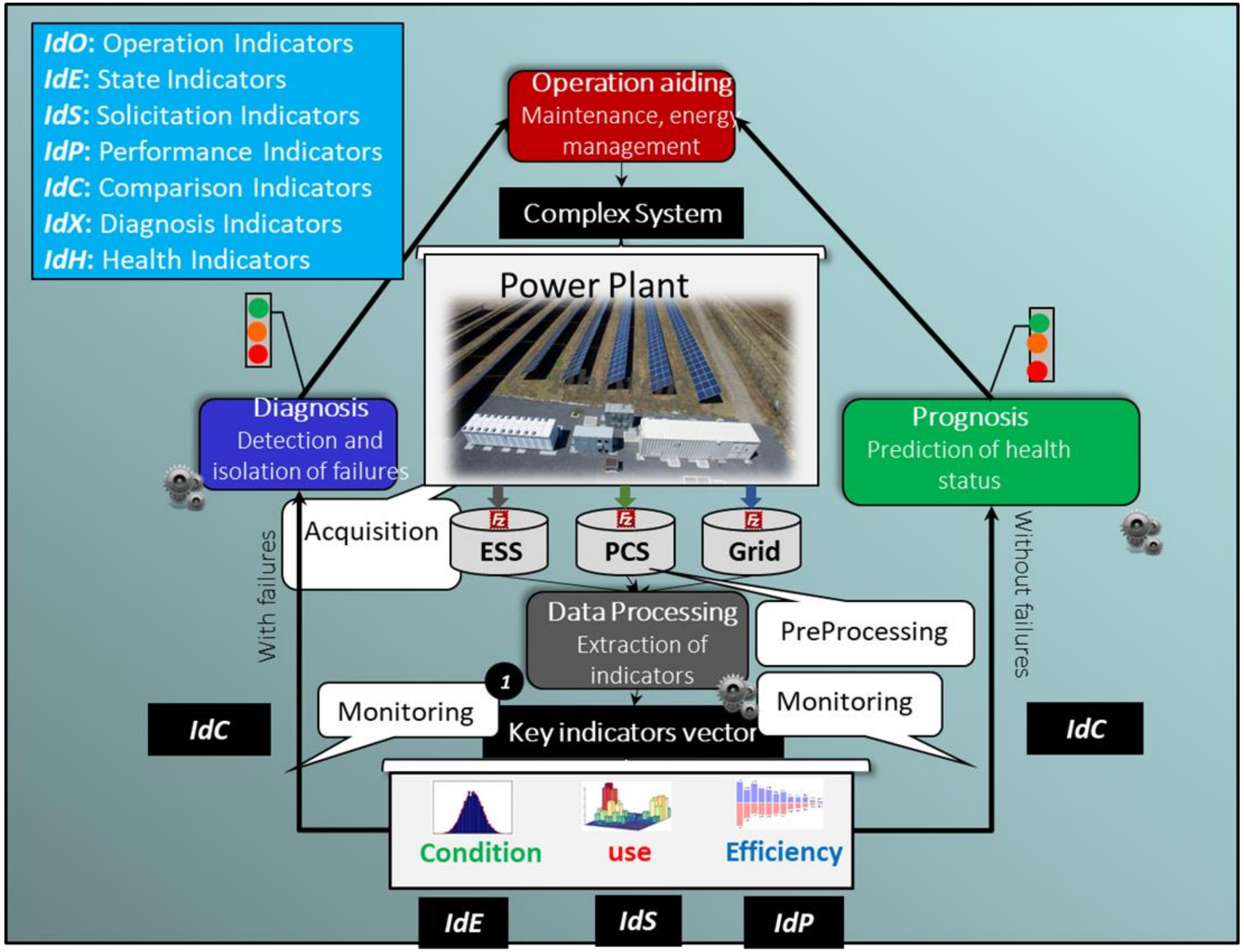


Fast reactive current injection (3-phase fault)



Tools for Battery Energy Storage System performance analysis

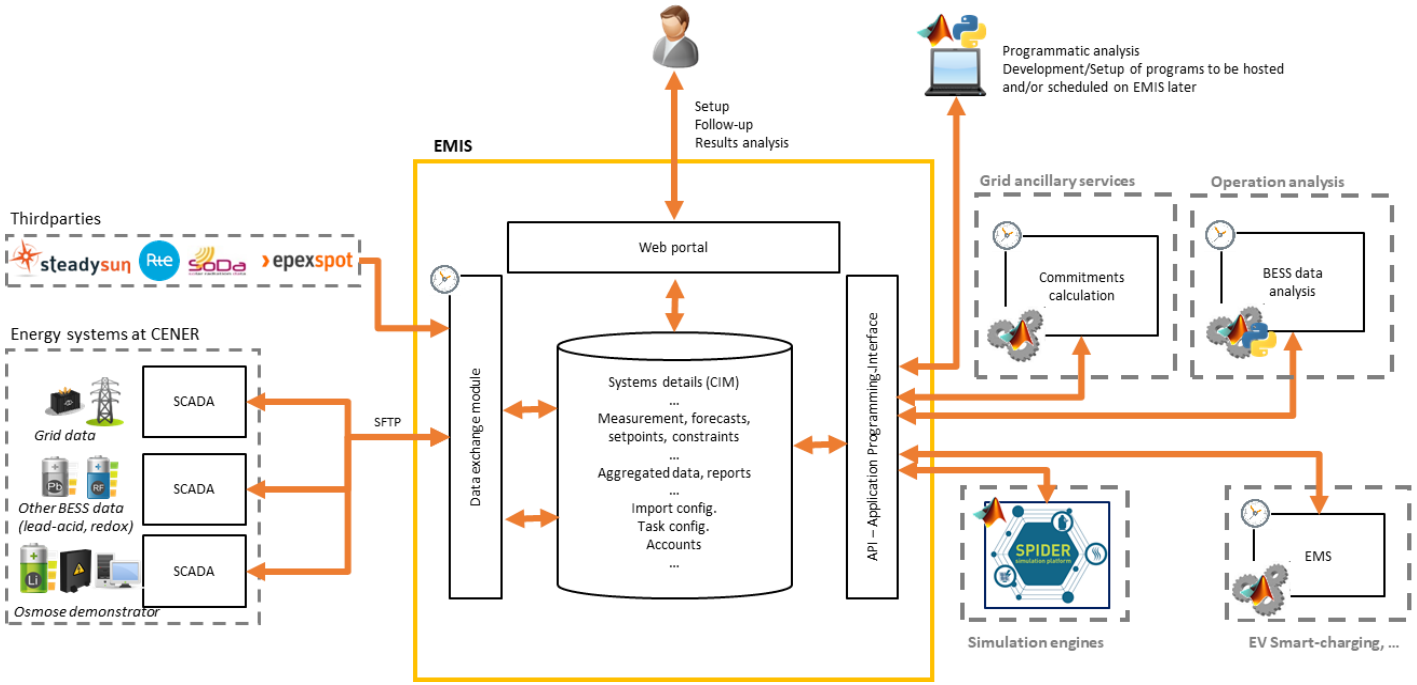
Different kinds of indicators were developed to analyse Battery Energy Storage System performances



Tools for Battery Energy Storage System performance analysis

Monitoring and collecting relevant data are of high importance

- Information system and database were developed during Osmose
- Getting the required data needs to be setup early during the project
- CIM compatible format (components, terminals, value set, quantity, timeseries)



Available after OSMOSE project to integrate new BESS systems and to analyse them

Tools for Battery Energy Storage System performance analysis

Required data from battery part of BESS to get in-depth analysis

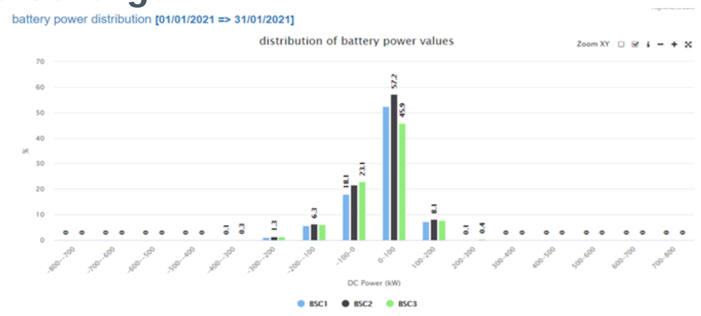
Useful batteries' information for each battery container	Units
DC voltage at container level (or better at rack level)	V
DC current at container level (or better at rack level)	A
DC power at container level	W (or kW)
Average ESS temperature (or better at rack level)	°C
Minimal temperature of battery cells	°C
Maximal temperature of battery cells	°C
Battery State-Of-Charge (SOC) for the battery or at rack level	%
Battery State-Of-Health (SOH) for the battery or at rack level	%
Maximal Battery State-Of-Charge (SOC) at module/rack level	%
Minimal Battery State-Of-Charge (SOC) at module/rack level	%
Minimal DC voltage of battery cells	V
Maximal DC voltage of battery cells	V
Maximal allowed discharge current	A
Maximal allowed charge current	A
Number of battery racks online / status of racks' contactors	integer
Alarms and warnings information if available	flags and text

+ data from BESS converter and auxiliaries, from EMS, from user settings and from grid

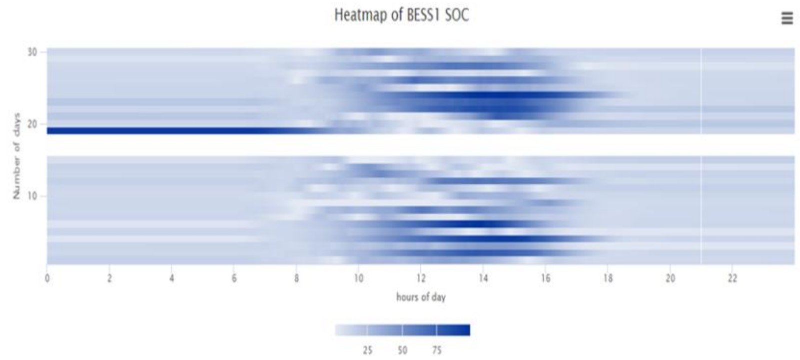
Tools for Battery Energy Storage System performance analysis

Computation of different indicators for BESS performance and ageing

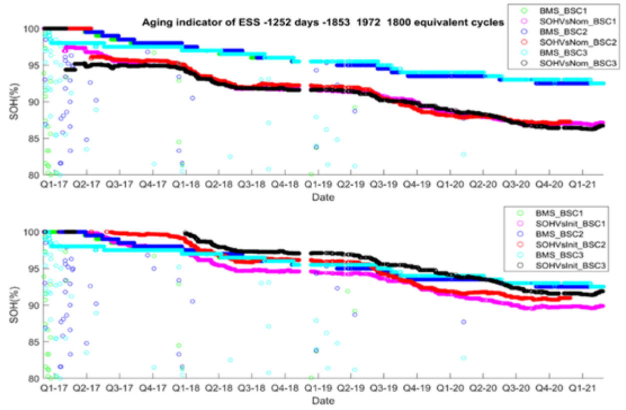
Power distribution in charge and discharge



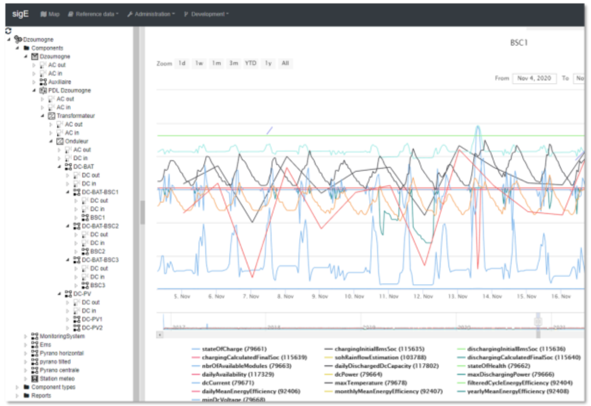
SOC heatmap



SOH computation (not for WP4 demo)



Dashboard, timeseries and reports



SOC and DOD distributions, efficiencies, availabilities, defaults ...

Key take aways

- The novel design and implementation of the Hybrid Flexibility Device and Master Control has been successfully developed and tested
- A new High Voltage Battery Storage has been manufactured and validated in factory and in real operation.
- Results (real operation and simulations) show the capability of the Hybrid Flexibility Device and the Master Control to provide the required grid services while coordinate different flexibility devices
- Next steps focus mainly in evaluate the implementation of the validated hybrid flexibility devices in the power grid as a commercial solution

Read more

Public deliverables

- D4.1 Comprehensive report on functionalities and services for the power system
- D4.2 Factory acceptance tests of the High Voltage Battery System
- D4.3 Hybrid Flexibility Device Implementation
- D4.4 Master control strategies
- D4.5 Real operation results evaluation

https://www.osmose-h2020.eu/resource-center/

OSMOSE

Final webinar series

Demonstration of grid forming capabilities and synchronisation services	*05 April*
Smart management of the grid: exploiting line temperature and load forecasts	*07 April*
Demonstration of close-to-real-time cross border flexibility market	*21 April*
Battery Energy Storage System: demonstration of multiple service provision, methods for design & control, data sharing	*26 April*
Optimal mix of flexibility in long-term scenarios	*03 May*
Market design modeling and analysis for flexibility	*04 May*

☞ To register: https://lnkd.in/ex8yyCPd /

Thank you for your attention!!

Questions?

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