OSMOSE
OPTIMAL SYSTEM-MIX OF FLEXIBILITY SOLUTIONS FOR EUROPEAN ELECTRICITY

ESIG GFM Workshop

08 June 2022

WP3: Grid forming by multi-services hybrid storage

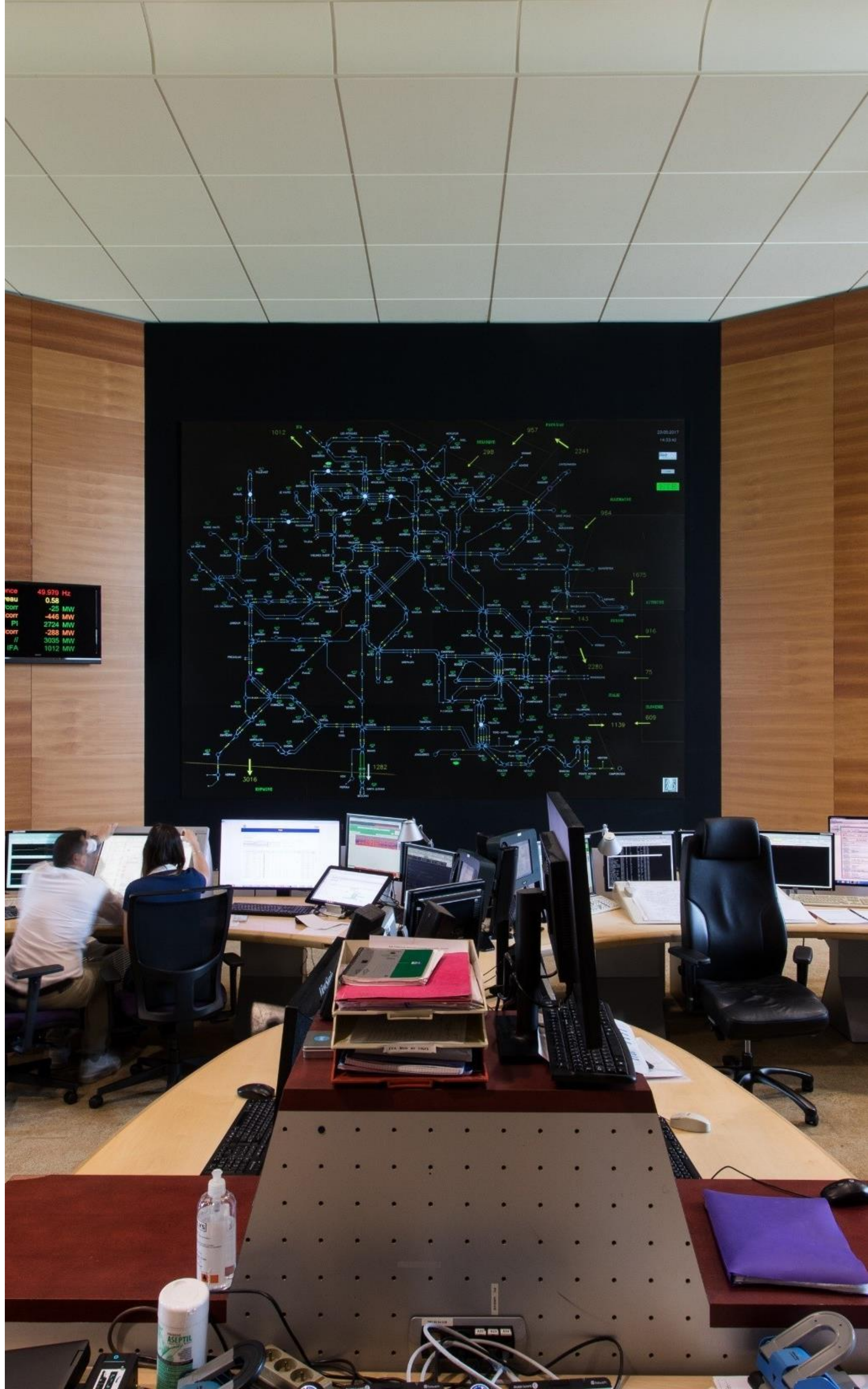
Carmen Cardozo (RTE)

The project has received funding from the European Union’s Horizon 2020 research and innovation program under grant agreement No 773406.

Agenda

1. **OSMOSE in a nutshell**
2. OSMOSE WP3: grid forming ESS demos
3. Grid forming capability & synchronization services
4. FAT RTE-Ingeteam demonstrator
5. Some EPFL experimental results

OSMOSE



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

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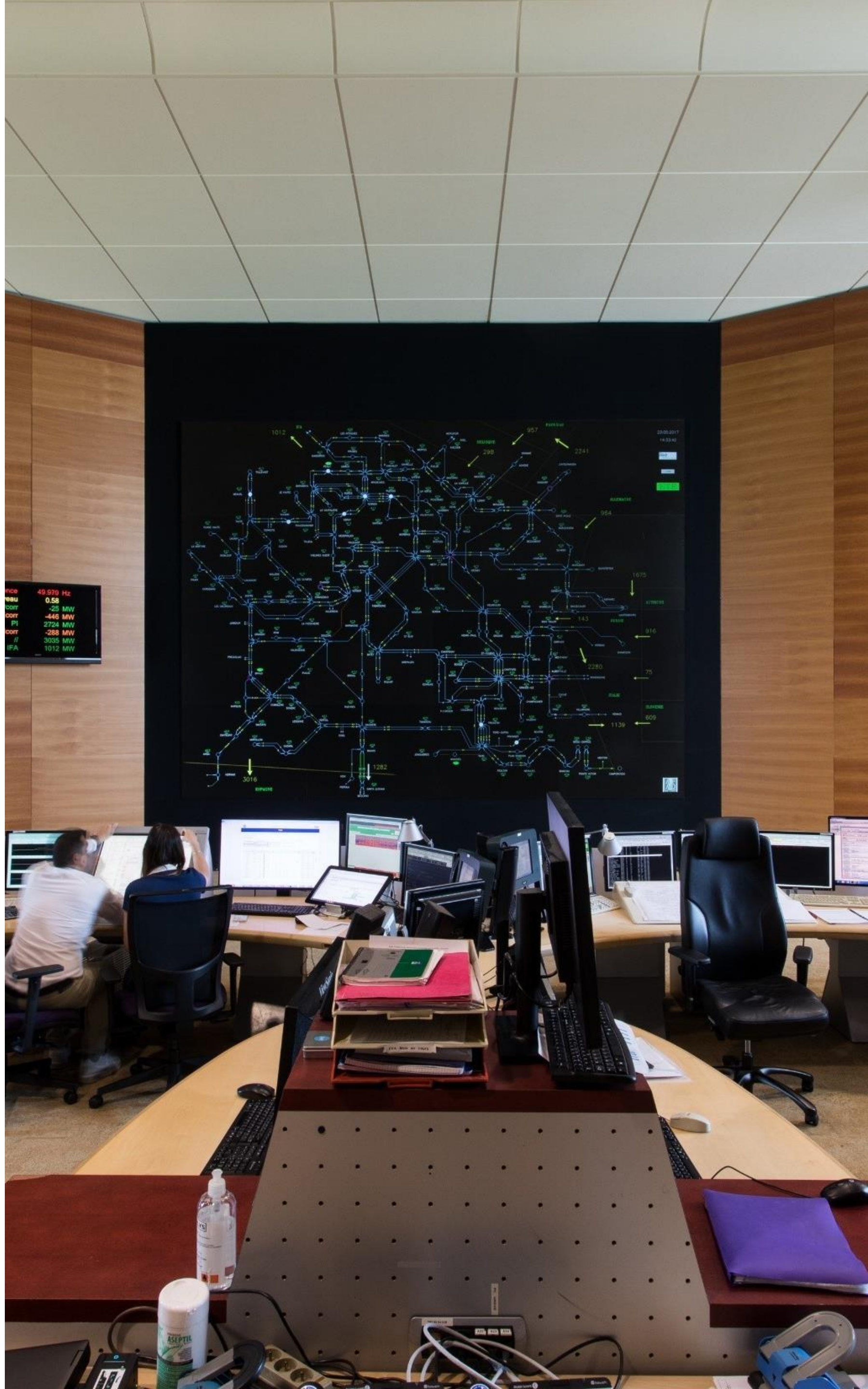


OSMOSE WP 3 demos

Ingeteam / Rte

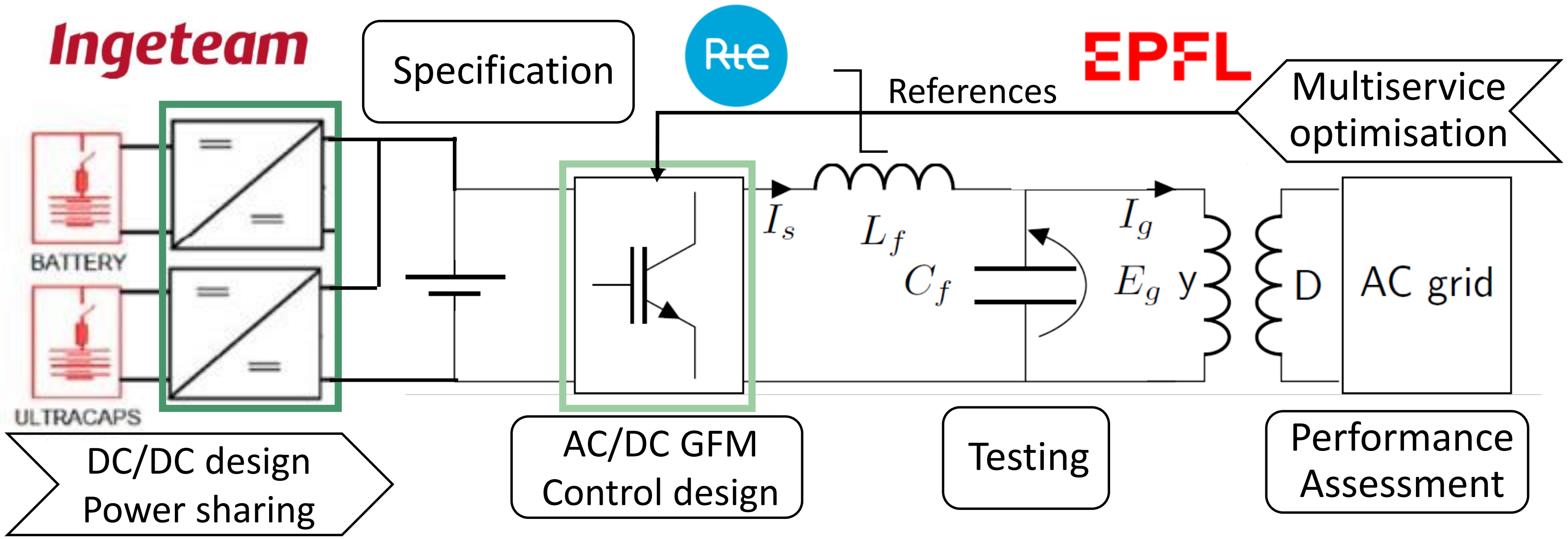
AC/DC	1000 kVA
Battery Li-ion	500 kW – 60 min
Supercapacitors	1000 kW – 10 s
Transformer	600 V – 20 kV

EPFL

AC/DC	720 kVA
Battery Li-Titan	720 kW – 45 min
Transformer	300 V – 21 kV

Figure 2.1: The 720kVA/500 kWh grid-connected BESS installed at the EPFL campus

OSMOSE WP 3 Contributions



Deliverables for further reading:

- *D3.1 Multi-service control algorithm for converters*
- *D3.2 Overall specifications of the demonstrations*
- *D3.3 Analysis of the synchronisation capabilities if BESS power converters*
- *D3.4 Quantification of multi-service synergy*

OSMOSE WP 3 Contributions

- Recommendations for specifying grid forming capability in EU grid codes. A minimal capacity must be deployed through connection requirements to avoid scarcity risk in operation and ensure system security.
- Definition of synchronisation services given by the synchronising power, system strength, inertial response and fault current. They can be decoupled from traditional ancillary services (frequency-related) at AC/DC converter level (TGFM) but also at device level in a hybrid ESS (DC power sharing strategies).
- Experimental validation that GFM capability can be provided with off-the-shelf MVA scale VSC interfacing ESS: a) without oversizing, b) while still providing traditional ancillary services and c) remaining robust to grid disturbances. RTE-Ingeteam proposed a GFM capability compliance testing procedure
- EPFL proposed a multi-service optimization framework covering for day-a-head to real-time, taking into account the unit’s operational constraints. Flexibility and ancillary service provision are compatible with GFM.
- Superior performance of grid-forming control compared to the grid-following one regarding the very short term frequency dynamics has been quantified with metrics proposed by EPFL based on local PMU measurements. This is achieved without any impact in the provision, hence revenues, of other ancillary and flexibility services.

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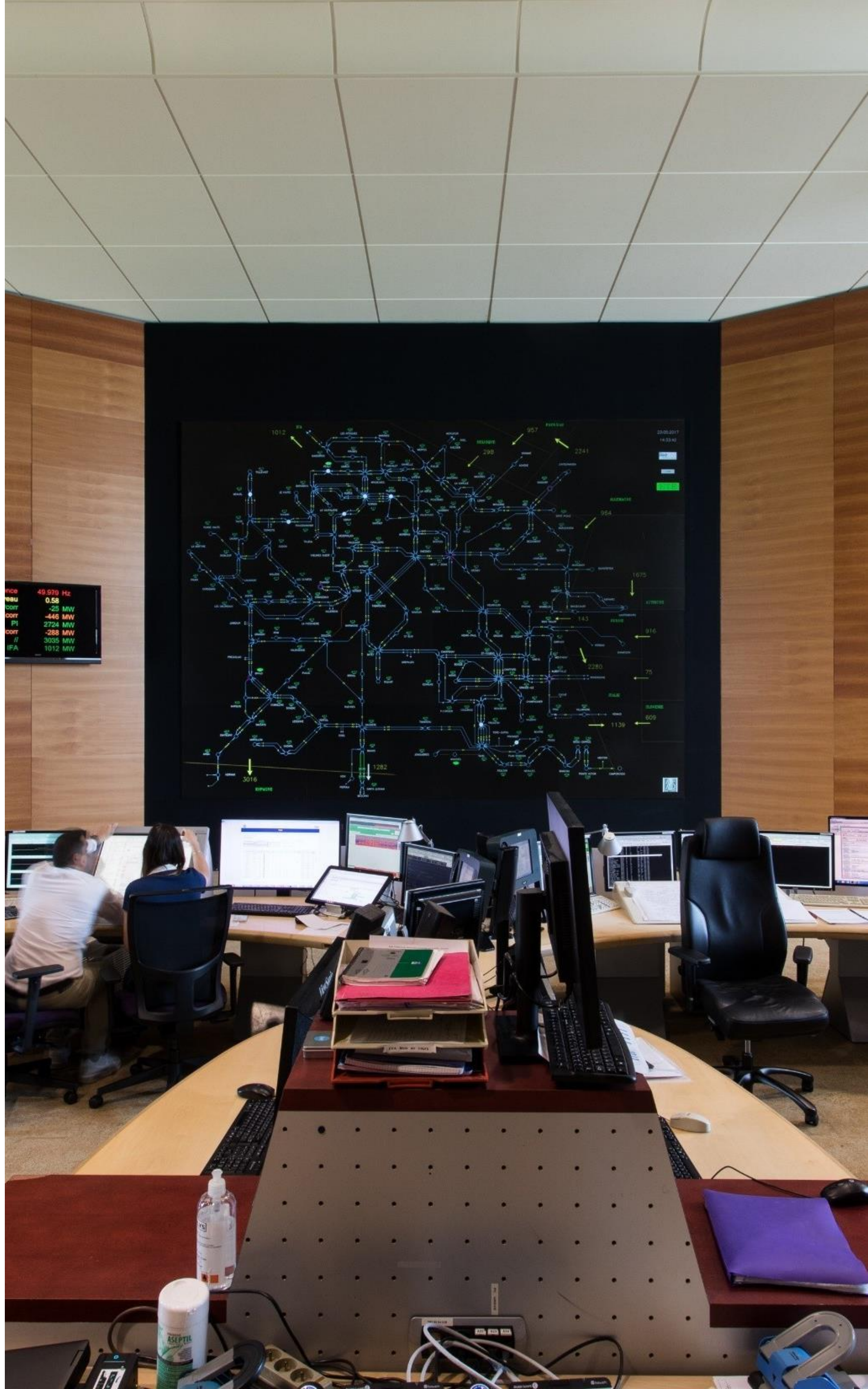
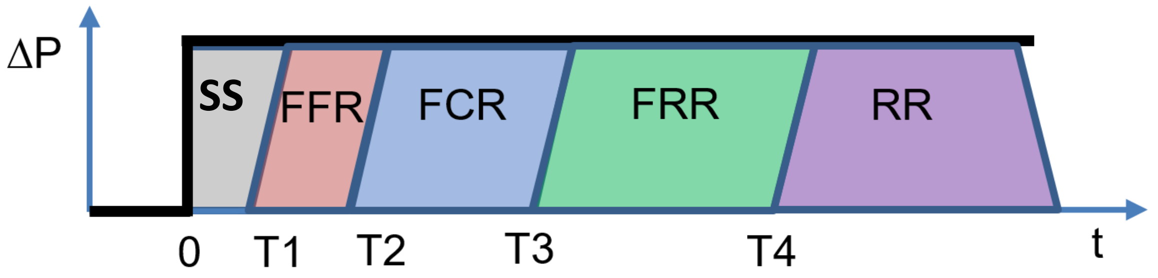


Specifying grid forming capability

A GFM unit shall, within its rated power and current, be capable of self-synchronise, stand-alone and provide synchronization services.

- By definition, a GFM does not rely on specific grid conditions to synchronise: it can operate at a wide range of short-circuit ratios and inertia levels.
- Synchronization services include a natural/ inherent/ immediate/ undelayed deployment of synchronising power, system strength, fault current and inertial response.
- Hence, a GFM unit will help others to maintain synchronism under stressful conditions, while still complying with the general requirements applying to the specific technology.
- No overload or capacity reservation is associated to the GFM capability, neither the provision of traditional ancillary services such as primary voltage and frequency regulation.

Defining synchronization services



T1= ~250ms-2s
T2=10-30s
T3= 5-15min
T4= 15-60 min

Fast Frequency Response FFR
Frequency Containment Reserve FCR
Frequency Restoration reserve FRR
Replacement Reserve RR

Non-frequency ancillary services[1]

Steady-state (minutes-hours)

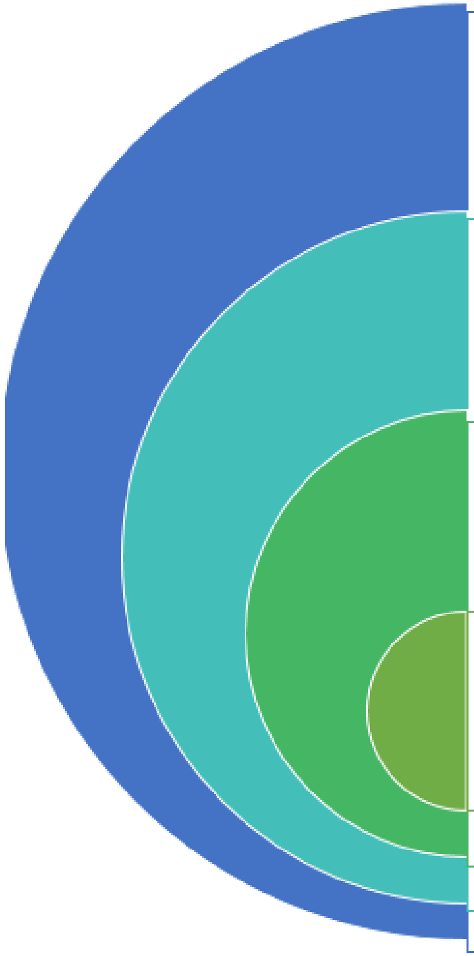
[1]Directive (UE) 2019/944

- Steady state voltage control (SSVC)
- Black start capability
- Island operation capability

Stability services (activation time <2s, variable sustained time depending on system needs seconds to minutes. Possible lower bound on activation time.)

- Fast reactive current injection (grid following)
- Short-circuit current (overload capability)
- Inertia for local grid stability

Types of grid forming units



Type 4	• Services provided: Type 3 + "High" fault current (more than 2 times Nominal) • Criticality: if protections fail to detect faults • Cost: high for converters since they have to be oversized, null for synchronous machines
Type 3	• Services provided: Type 2 + Inertial response • Criticality: When system inertia decreases globally • Cost: limited due to the need of an energy buffer from a few seconds to 1min
Type 2	• Services provided: Type 1 + Synchronising power profile • Criticality: When system inertia decreases locally • Cost: very limited due to the need of an energy buffer <1 s. Other FFR resource are supposed to be available elsewhere to take over.
Type 1	• Service provided: Stand alone + System strength + "Low" fault current (within ratings, usually equal or close to nominal). Operate wide range of SCR • Criticality: When system strength decreases locally • Cost: null, only software

Synchronous Machine

VSC - ESS

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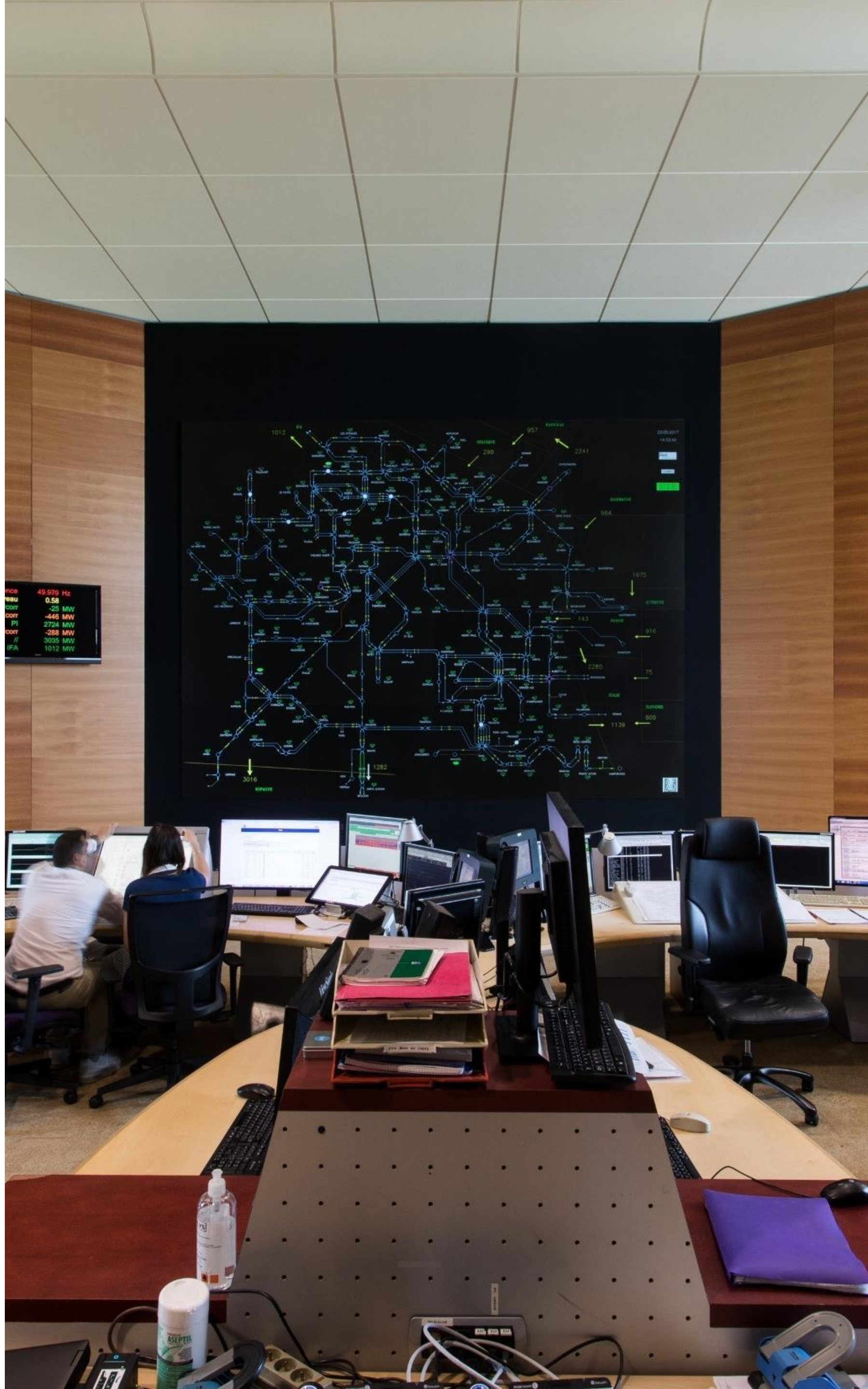
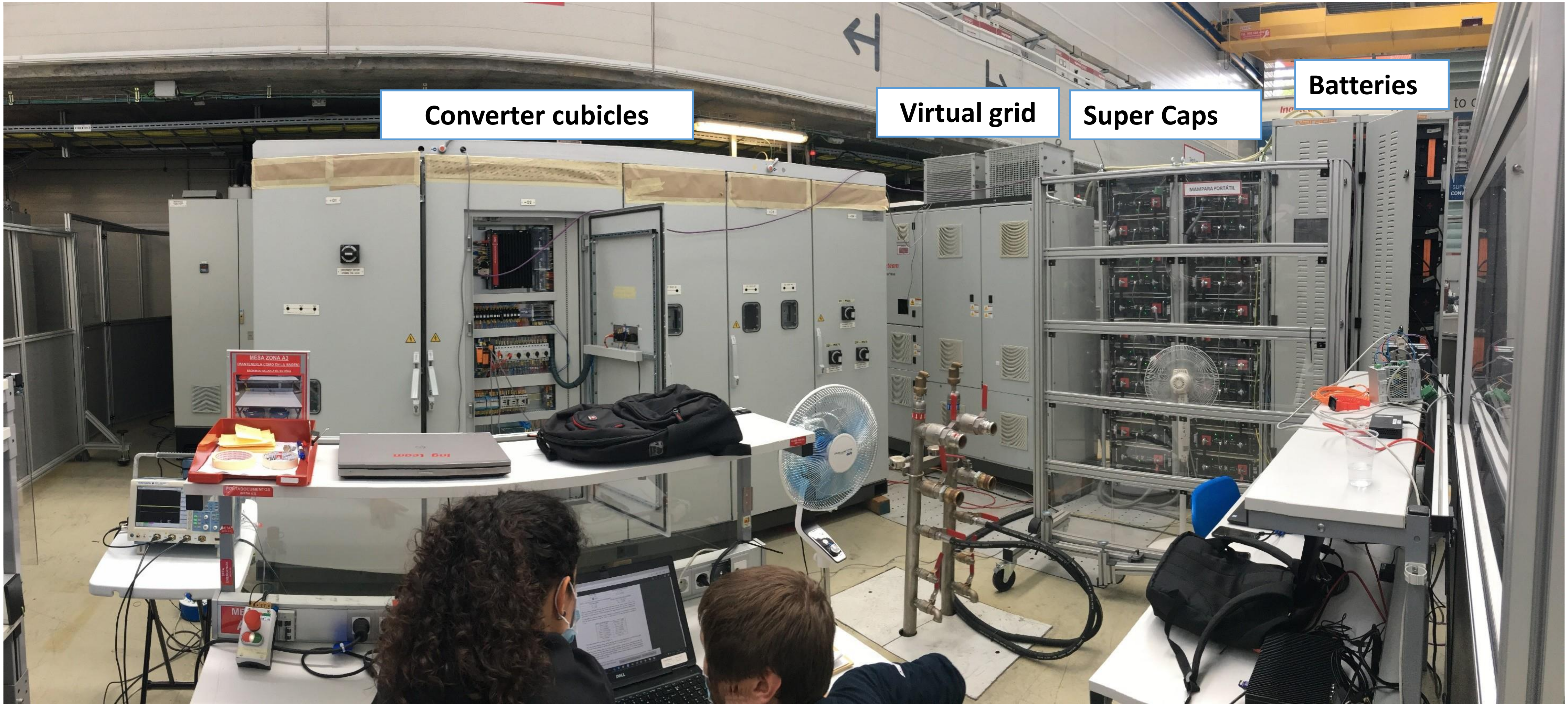


OSMOSE

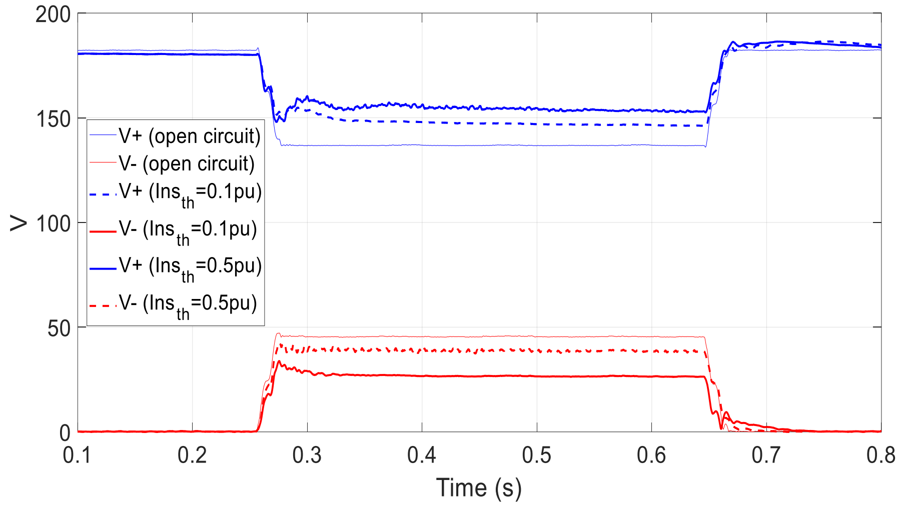
OSMOSE WP3 Contributions – RTE/Ingeteam PHIL FAT

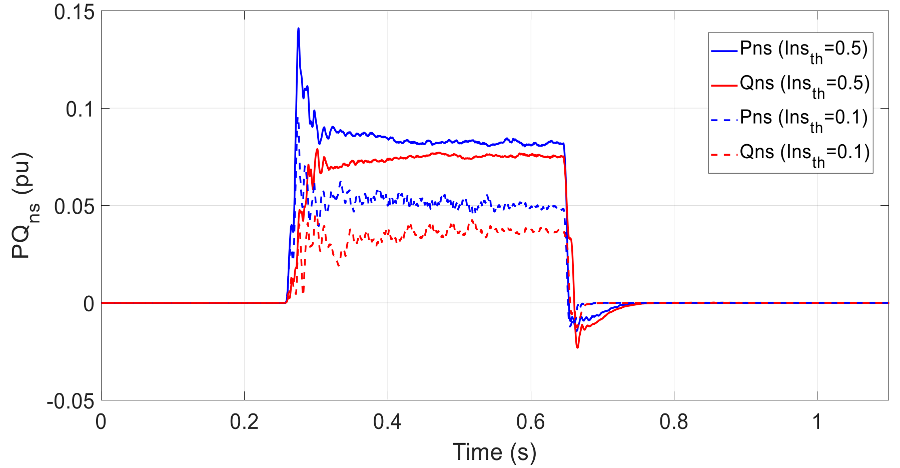


OSMOSE WP3 Contributions – RTE/Ingeteam PHIL FAT

AC/DC grid forming control design

- Negative sequence threshold virtual impedance (NS-TVI) to improve the grid forming control robustness to asymmetrical faults and define settable prioritisation between the positive and negative sequence.





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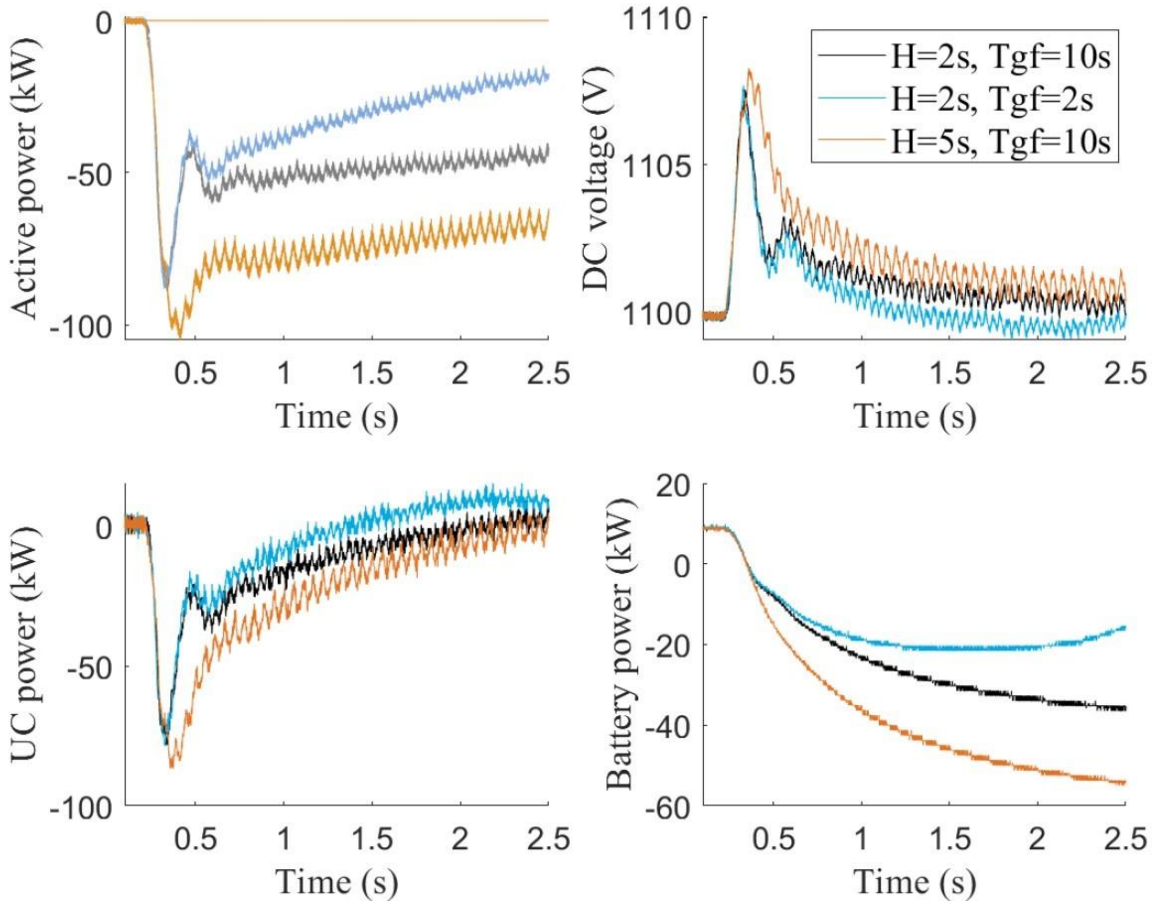

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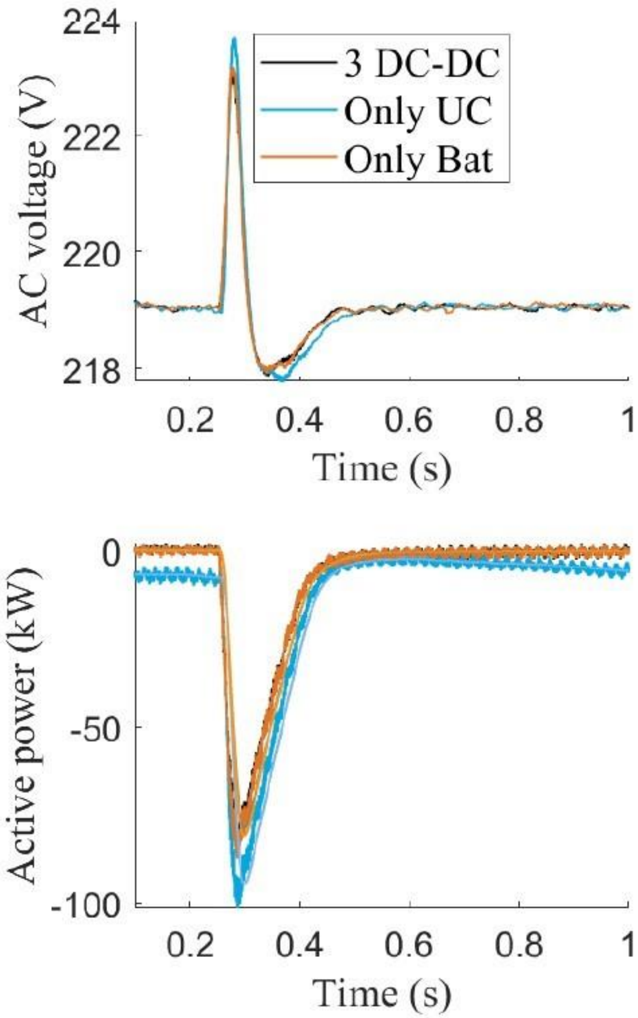
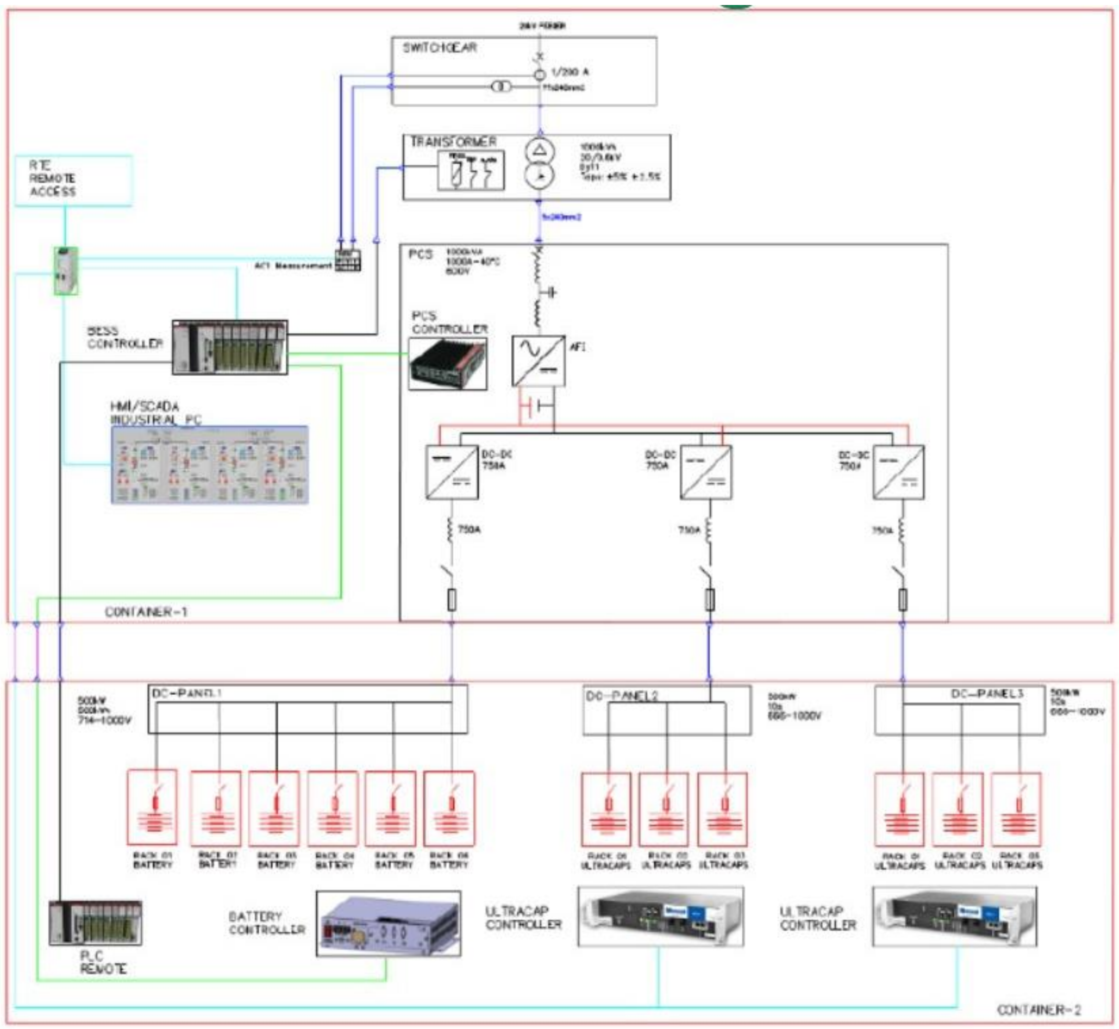
DC/DC control design in a HESS

- Decoupling of the those services at device level through DC power sharing strategies: fast transients are fed by the UC, smoothing the battery power output. Energy intensive flexibility services are provided by the battery.



RTE/Ingeteam experimental setup



Ingeteam implemented one of the MIGRATE WP3 grid forming controls in the Voltage Source Converter interfacing a hybrid ESS (HESS) to the grid.

A 1 MVA fully containerised solution was specifically built for the project and connected to a 20 kV feeder in a RTE substation, including:

- a medium voltage switchgear cubicle,
- four lithium-ion battery racks (0.5 MVA 60 min)
- six ultra-capacitor (UC) racks (total of 1MW-10s)
- 3x500 kW DC/DC converters,
- 1 MVA AC/DC GFM converter,
- 1 MVA 0.6/20 kV transformer.

A fire incident during commissioning prevented this Demo to be ultimately operated grid-connected

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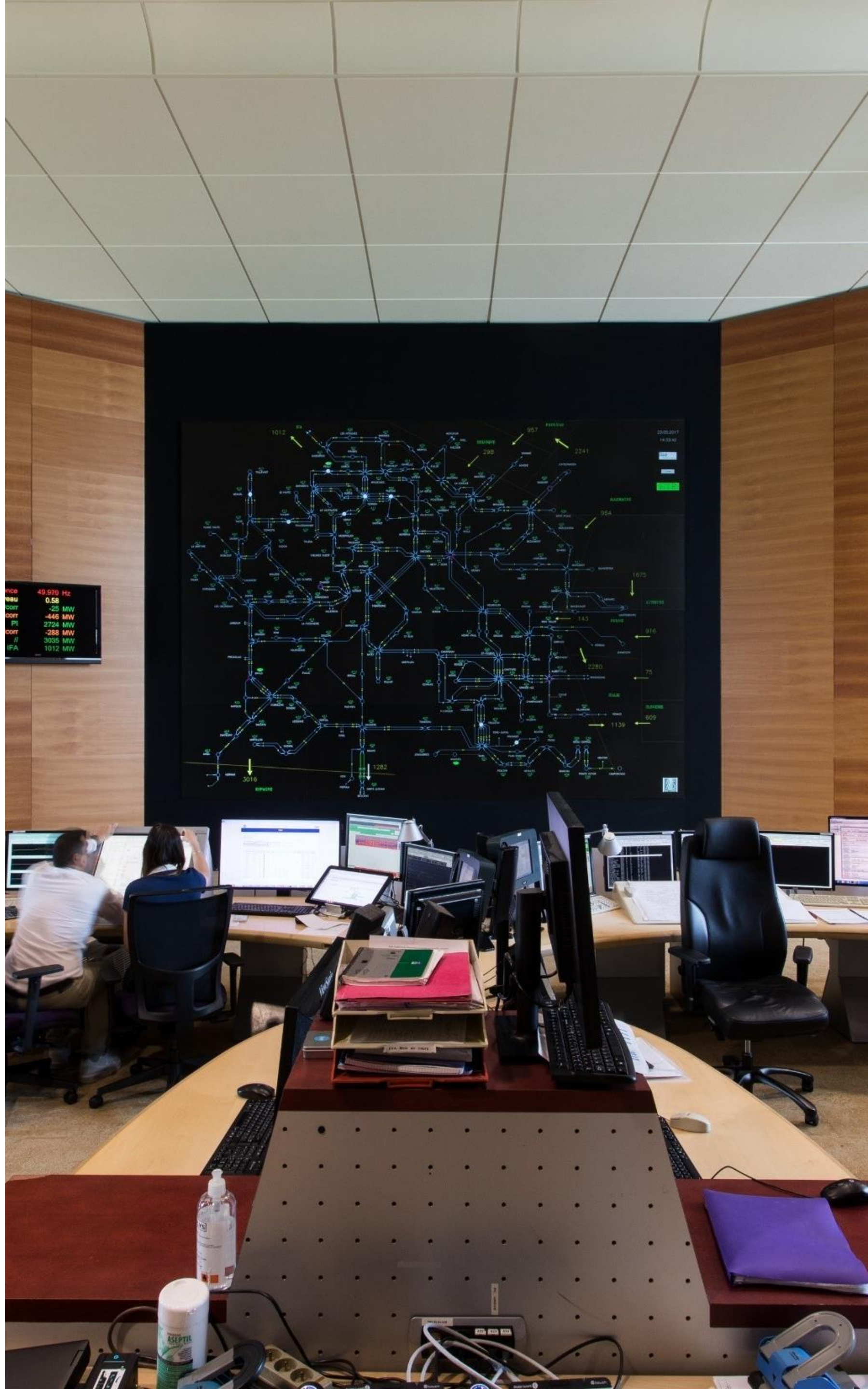


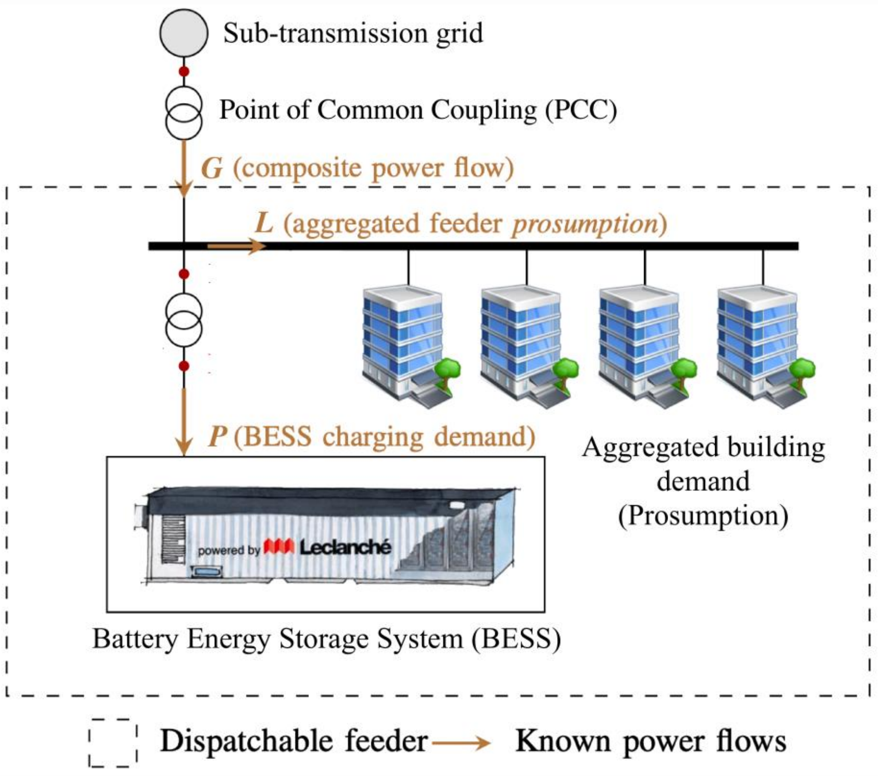
EPFL experimental setup

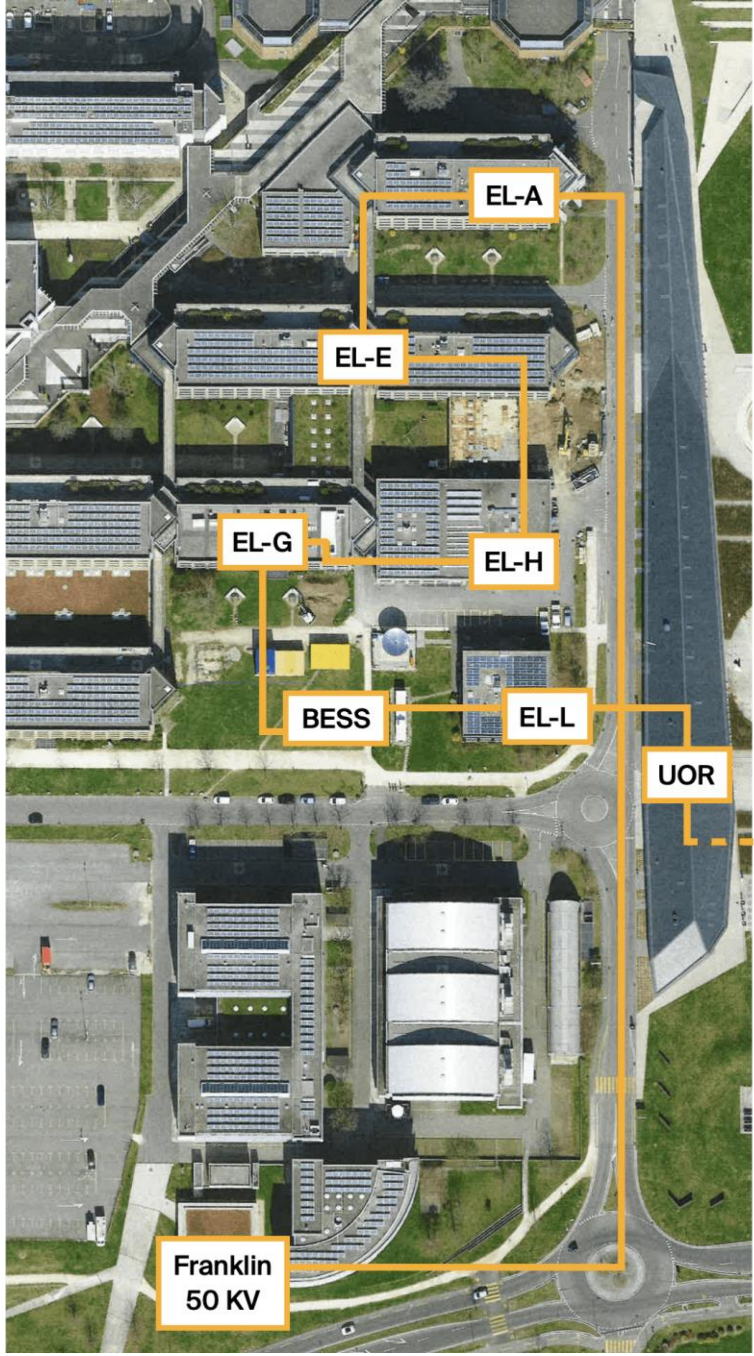
MV feeder (21 kV):

- 50/21 kV primary substation (Franklin);
- 140 kW base load;
- 105 kWp distributed PV generation;
- 720 kVA / 560 kWh BESS.

Measuring infrastructure:

- Distributed PMU sensing;
- Reporting time 20 ms;
- Accuracy σ: 0,001 deg (18μrad)





Performance assessment

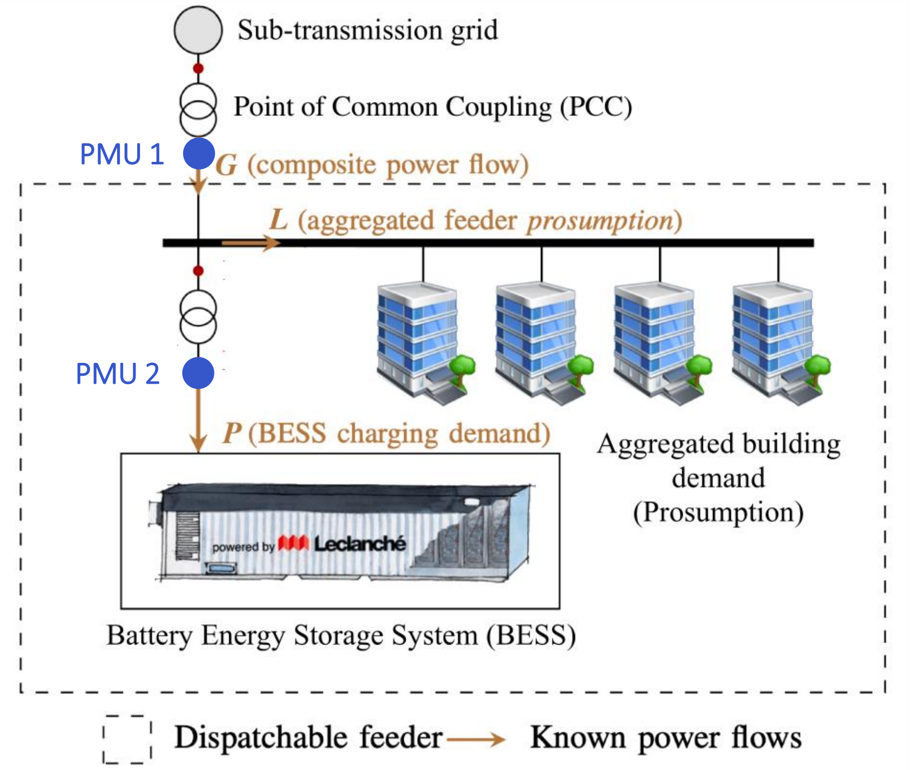
Post-process analysis of the local grid frequency associated to Grid-forming/Grid-following experimental sessions

Relative Rate-of-Chang-of-Frequency (rRoCoF)

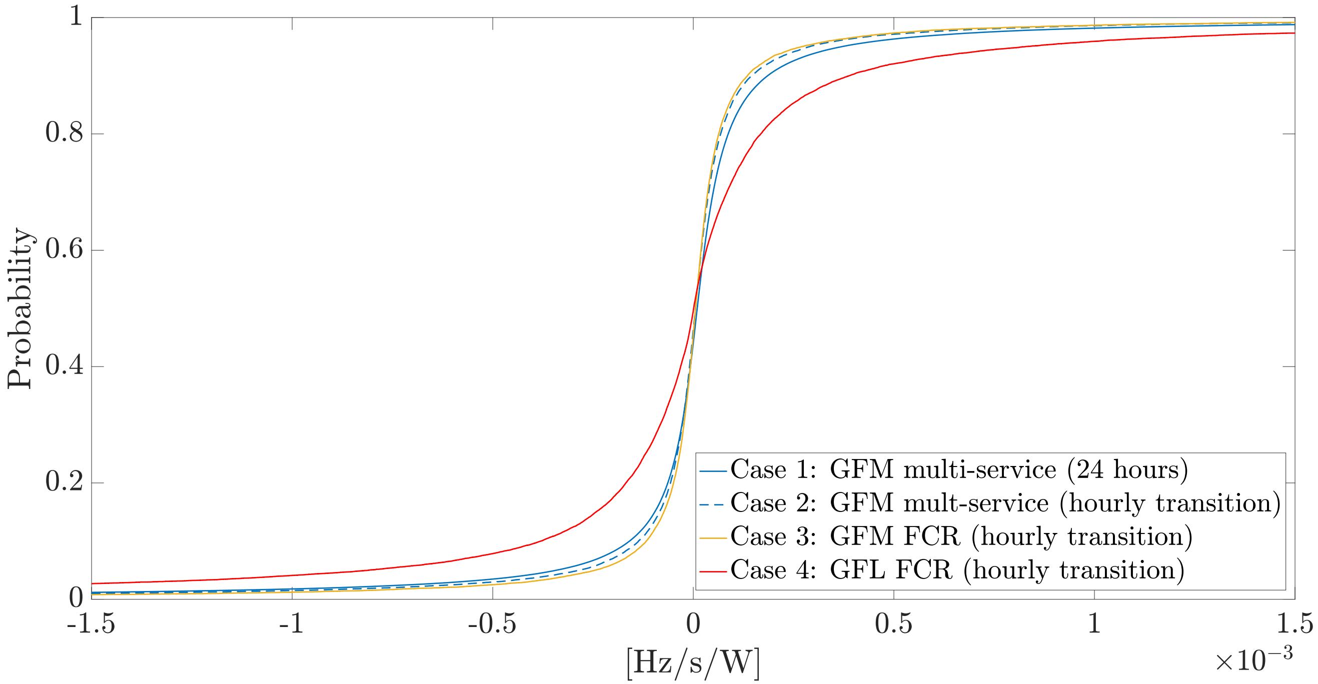
$$rRoCoF = \left|\frac{\Delta f_{pcc}/\Delta t}{\Delta P_{BESS}}\right|$$

where $\Delta f_{pcc}/\Delta t$ is the PMU-measured RoCoF at the PCC corresponding to a variation of the BESS power ΔP_{BESS}.

This metric is independent from the actual frequency variation since the RoCoF is divided by the BESS regulation power.

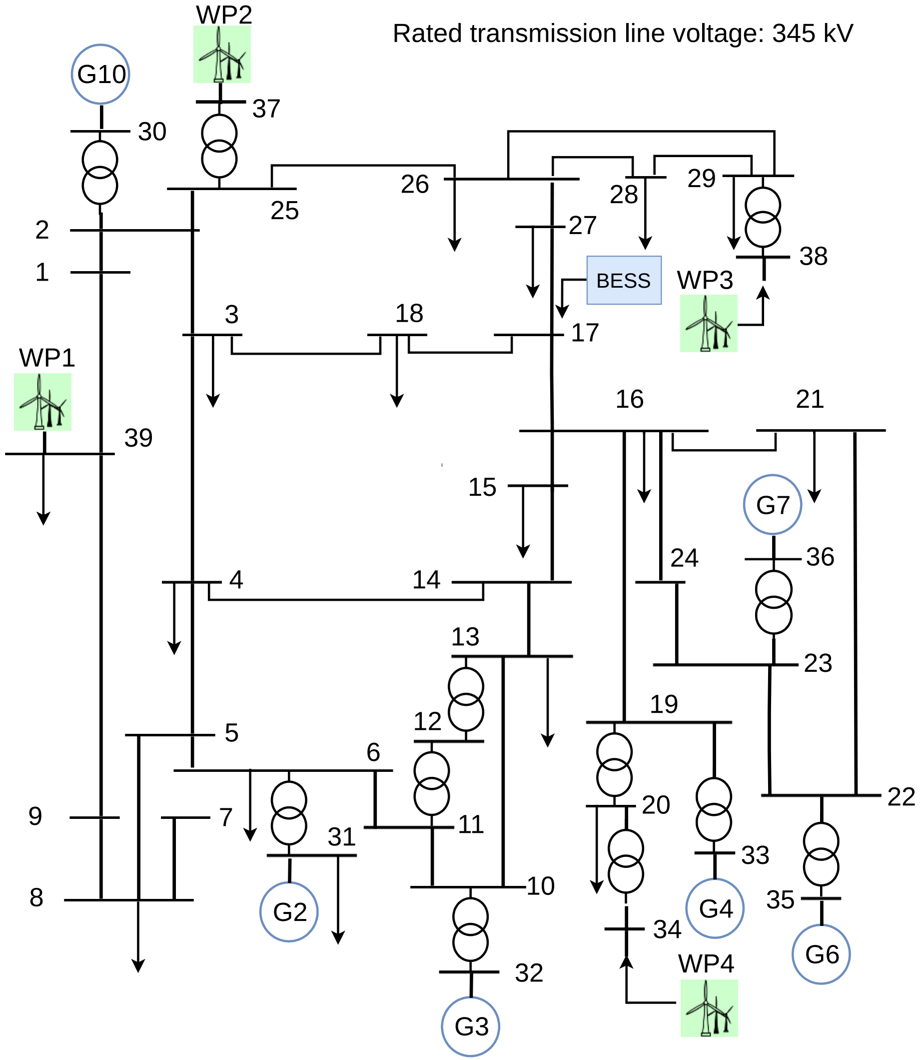


OSMOSE WP3 Contributions – EPFL demo



- **Case 1:** the 24 hour-long experiment with GFM-controlled BESS providing multiple services.
- **Case 2:** 15-minute window around the hourly transition (i.e., 00:00 CET) for the same day-long experiment.
- **Case 3:** dedicated 15-minute experiment around the hourly transition with the GFM-controlled BESS providing only FCR (droop of 1440 kW/Hz).
- **Case 4:** a dedicated 15-minute experiment around the hourly transition with the GFL-controlled BESS is providing only FCR (droop of 1440 kW/Hz).

Scale up: low-inertia IEEE 39 bus RTS



- Capacity of BESS: 225 MVA/175MWh
- 6 synchronous machines : 6000 MWA
- 4 wind farms: 4000 MWA
- 19 PMUs implementing the same phasor extraction process (i.e., e-IpDFT) used in C37.118-compliant devices are installed in each load bus.
- Full-replica time-domain dynamic models of the low-inertia IEEE 39-bus power grids are open-sourced https://github.com/DESL-EPFL/
- Model running on the Opal-RT eMEGAsim Real-Time Simulator.

Further Reading

Deliverables

- D3.1 Multi-service control algorithm for converters
- D3.2 Overall specifications of the demonstrations
- D3.3 Analysis of the synchronisation capabilities if BESS power converters
- D3.4 Quantification of multi-service synergy

Publications RTE - Ingeteam

- Enhanced TVI for Grid Forming VSC under Unbalanced Faults. Published on Energies.
- OSMOSE WP3: Factory Acceptance Test of the grid forming demonstrator. Presented in SIW 2020.
- OSMOSE Grid-Forming performance assessment within multiservice storage connected to the transmission grid. Cigre 2020.
- Upgrade of a grid-connected storage solution with grid-forming function. Presented in SIW 2019.
- Performance assessment of Synchronous Condensers vs Voltage Source Converters providing grid-forming functions. PowerTech 2021.

Further Reading

Publications EPLF

- F. Gerini, Y. Zuo, R. Gupta, E. Vagnoni, R. Cherkaoui, and M. Paolone, “Optimal Grid-Forming Control of Battery Energy Storage Systems Providing Multiple Services: Modeling and Experiment Validation.” Accepted at PSCC 2022.
- Z. Yuan, A. Zecchino, R. Cherkaoui and M. Paolone, "Real-Time Control of Battery Energy Storage Systems to Provide Ancillary Services Considering Voltage-Dependent Capability of DC-AC Converters," in IEEE Transactions on Smart Grid, vol. 12, no. 5, pp. 4164-4175, Sept. 2021.
- A. Zecchino, Z. Yuan, F.Sossan, R. Cherkaoui, and M. Paolone, “Optimal provision of concurrent primary frequency and local voltage control from a BESS considering variable capability curves: Modelling and experimental assessment,” Electric Power Systems Research, Volume 190, 2021, 106643.
- Y. Zuo, Z. Yuan, F. Sossan, A. Zecchino, R. Cherkaoui, and M. Paolone, “Performance assessment of grid-forming and grid-following converter-interfaced battery energy storage systems on frequency regulation in low-inertia power grids,” Sustainable Energy, Grids and Networks, Volume 27, 2021, 100496.
- A. Zecchino, F. Gerini, Y. Zuo, R. Cherkaoui, M. Paolone and E. Vagnoni, "Local Effects of Grid-Forming Converters Providing Frequency Regulation to Bulk Power Grids," 2021 IEEE PES Innovative Smart Grid Technologies - Asia (ISGT Asia), 2021, pp. 1-5.
- Y. Zuo, M. Paolone, and F. Sossan, “Effect of voltage source converters with electrochemical storage systems on dynamics of reduced-inertia bulk power grids,” Electric Power Systems Research, Volume 189, 2020, 106766.
- E. Namor, F. Sossan, R. Cherkaoui and M. Paolone, "Control of Battery Storage Systems for the Simultaneous Provision of Multiple Services," in IEEE Transactions on Smart Grid, vol. 10, no. 3, pp. 2799-2808, May 2019, doi: 10.1109/TSG.2018.2810781.
- Y. Zuo, F. Sossan, M. Bozorg and M. Paolone, "Dispatch and Primary Frequency Control with Electrochemical Storage: A System-wise Verification," 2018 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT-Europe), 2018, pp. 1-6.

THANK YOU

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And now
Q&A!

Visit OSMOSE for further information

www.osmose-h2020.eu

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