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ISGAN
International Smart Grid Action Network
ISGAN Academy Webinar

Demonstration of grid forming capabilities and synchronisation services (OSMOSE project)

05. 04. 2022
Online Webinar

ISGAN in a Nutshell

ISGAN is the short name for the *International Energy Agency* (IEA) *Technology Collaboration Programme* (TCP) for a Co-operative Programme on Smart Grids (ISGAN – *International Smart Grids Action Network*).

It is also an initiative of the *Clean Energy Ministerial* (CEM) and was formally established at CEM2 in Abu Dhabi, in 2011 as an Implementing Agreement under a framework of the *International Energy Agency* (IEA).

The *International Smart Grid Action Network* (ISGAN) creates a strategic platform to support high-level government attention and action for the accelerated development and deployment of smarter, cleaner electricity grids around the world.

ISGAN in a Nutshell

ISGAN currently consists of 27 Contracting Parties.
Their nominated representatives form the Executive Committee headed by the Presidium, assisted by two co-Secretariats and the Operating Agent of ISGAN.

Co Secretariat

AUSTRIAN INSTITUTE OF TECHNOLOGY

ISGAN Presidium

ISGAN Executive Committee

Co Secretariat

Korea Smart Grid Institute

Vision

ISGAN's vision is to accelerate progress on key aspects of smart grid policy, technology, and investment through voluntary participation by governments and their designees in specific projects and programs. Its activities center foremost on those aspects of the smart grid where governments have regulatory authority, expertise, convening power, or other leverage, focusing on five principal areas:

- Policy standards and regulation
- Finance and business models
- Technology system development
- Workforce skills and knowledge
- Users and consumers engagement

ISGAN facilitates dynamic knowledge sharing, technical assistance, peer review and, where appropriate, project coordination among its Contracting Parties.

Value proposition

ISGAN Virtual Learning

- Offer the ISGAN community of high level engineers and decision makers a means of rational and efficient continuous technical skills complement and update in the field of smart grids
- ISGAN Virtual Learning proposes e-learning core modules dealing with the entire value chain of smart grid
- Fundamentals and further reading modules are also provided as appendices
- Webinars organized every two months or co-hosted with the Clean Energy Solutions Center

ISGAN Virtual Learning

Operating Agent

ISGAN Website: www.iea-isgan.org

Demonstration of grid forming capabilities and synchronisation services

Within the context of service provision to future power systems hosting massive amount of inverter-based renewable/stochastic generation, 2 demonstrators of the OSMOSE project have shown that grid forming capability can be provided from off-the-shelf equipment.

The speakers:

- Carmen Cardozo, Research Engineer, RTE R&D
- Markel Zubiaga , Research Engineer, Ingeteam R&D
- Mario Paolone, Professor, EPFL

Please, use the **Q&A tool** to pose questions, the speakers will answer at the end of the presentation.

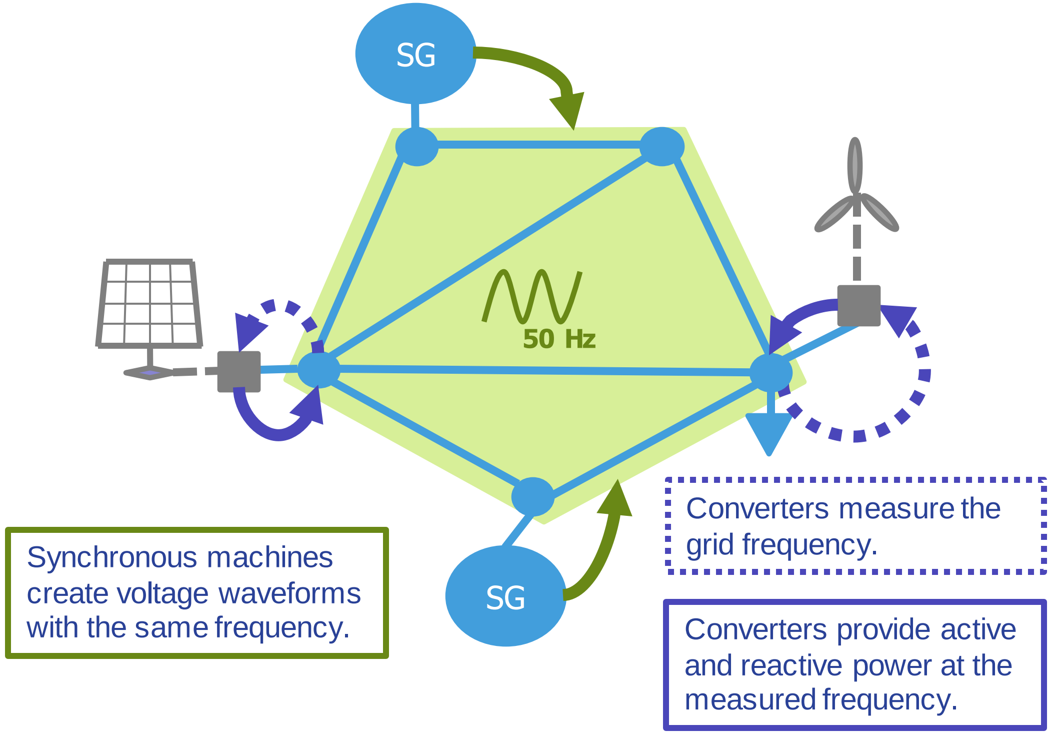
The recording will be available through the **ISGAN YouTube channel.**

Agenda

- **Introduction to OSMOSE WP3 and demos**
- **Presentation of the RTE-Ingeteam demo**
  - Specification of grid forming capability
  - AC/DC converter control design, grid forming controls and DC side management strategies
  - Grid forming capability compliance verification
- **Presentation of the EPFL Demonstrations**
  - Description of the control framework and experimental setup
  - Performance assessment of grid-forming vs grid following units in the EPFL demonstrator.
  - Extension of the analysis to the inertia-reduced IEEE 39 bus transmission system benchmark.
- **Conclusion & key take-away**

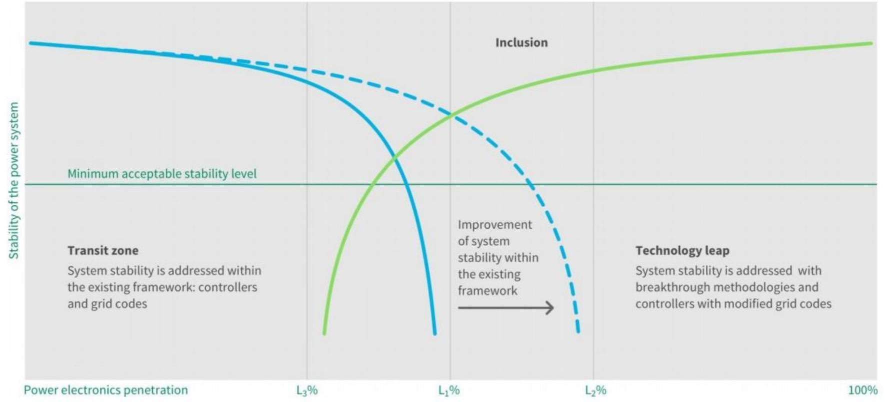
Context & backgrounds

- **Inverter-based resources (IBR)** currently connected to the grid are grid following:



MIGRATE

ISGAN INTERNATIONAL SMART GRID ACTION NETWORK



- How much IBR before unstable behaviour?
- Can we operate a system 100% IBR?
  - Redefined system needs, and
  - Proposed various **grid forming (GFM)** controls
- Many more are now available in the literature
- 2 high power demonstrations ABB & Siemens
- GC0137: Minimum Specification Required for Provision of **Great Britain Grid Forming (GBGF)**

Specific Objectives

- To progress on the common understanding on the definition of the grid forming capability.

- To demonstrate:
  - the technical feasibility of providing grid forming capability with commercially available power-electronics interfaced **energy storage systems (ESS)**,
  - that this solution can be industrially deployed in **voltage source converter (VSC)** without oversizing such that it is economically viable, and
  - that the GFM ESS contribution to power system stability can be quantified by means of external measurements without a detailed knowledge of specific low-level controls.

Demonstrators overview

Ingeteam / Rte

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

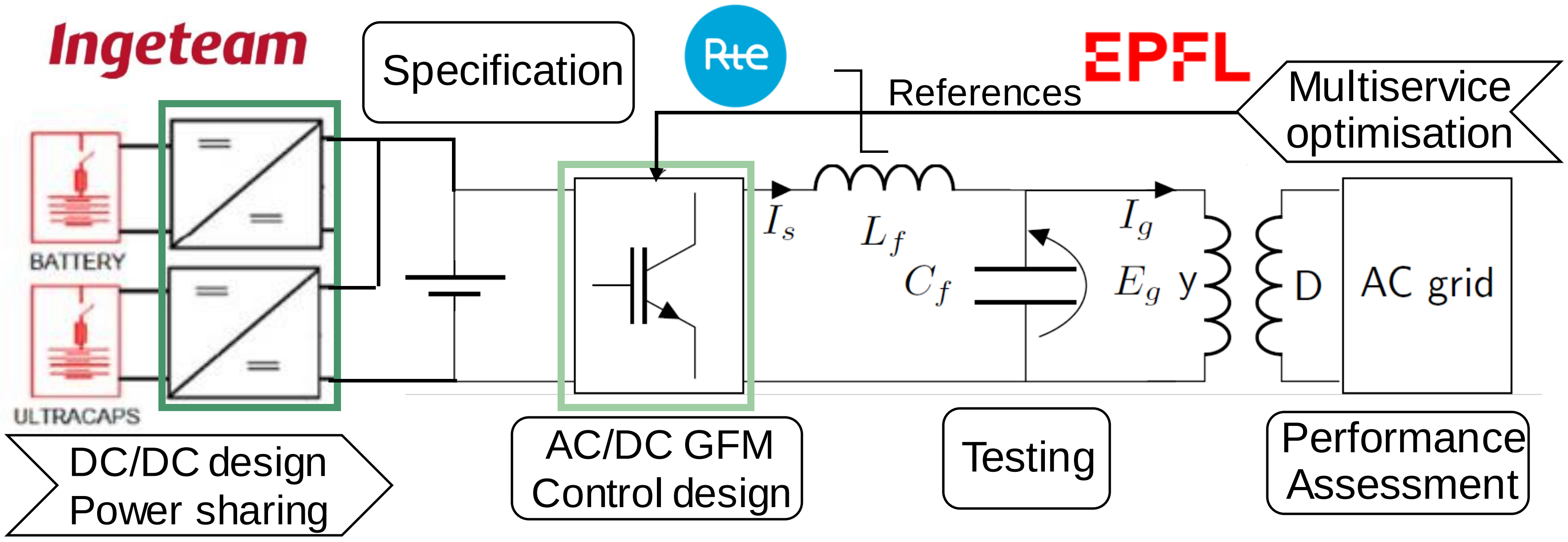
EPFL

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

[1] D3.2 Overall specification of the demos

Scope of the contributions



Deliverables for further reading:
- *[2] D3.1 Multi-service control algorithm for converters*
- *[3] D3.3 Analysis of the synchronisation capabilities if BESS power converters*
- *[4] D3.4 Quantification of multi-service synergy*

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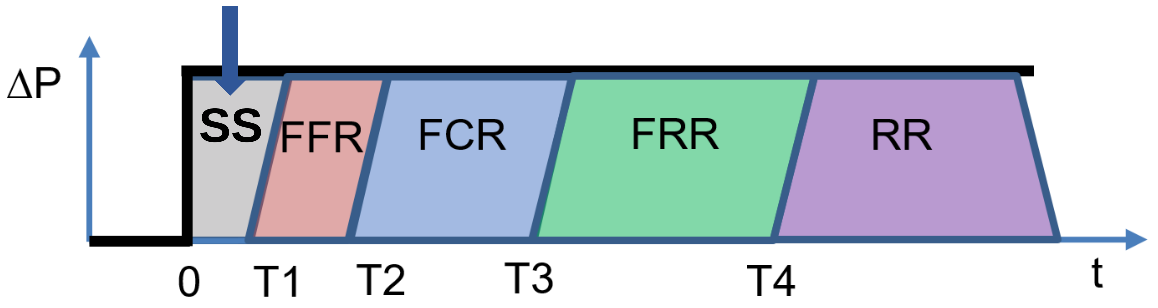
Definition of grid forming capability

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.

Definition of synchronisation 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

Proposed types of grid forming units

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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

Synchronous Machine

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

VSC - ESS

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

RTE-Ingeteam demo description

Ingeteam / Rte

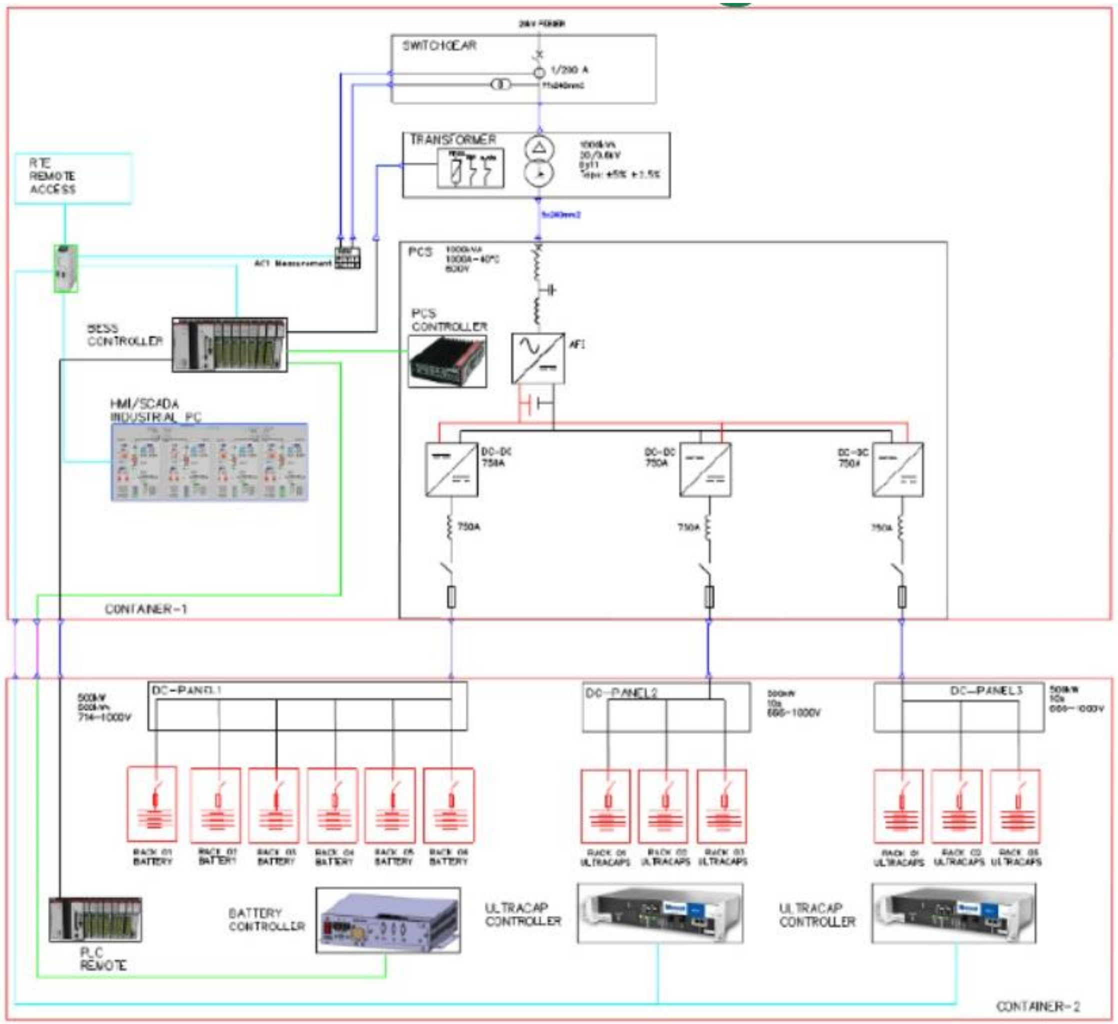
Ingeteam implemented one of the MIGRATE grid forming controls in the Voltage Source Converter interfacing a **hybrid ESS (HESS)** to the grid.

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

- 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 medium voltage switchgear cubicle.

RTE-Ingeteam demo description

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



Contributions in control design

AC/DC grid forming control design

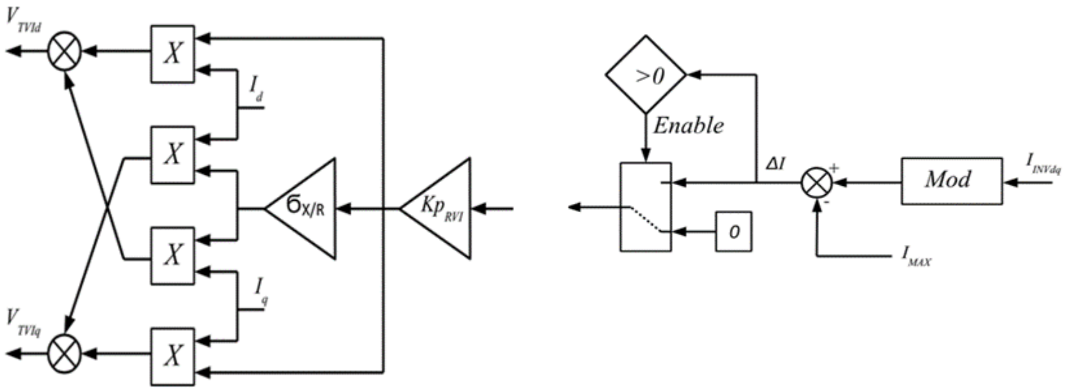
- Inclusion of a **negative sequence (NS)** component to the **threshold virtual impedance (TVI)** current limitation strategy to improve the grid forming control robustness to asymmetrical faults and define settable prioritisation between the positive and negative sequence.
- Decoupling between the synchronisation (inertia) and the frequency-related services (Fast Frequency Response or Frequency Containment Reserve) at the AC/DC converter level.

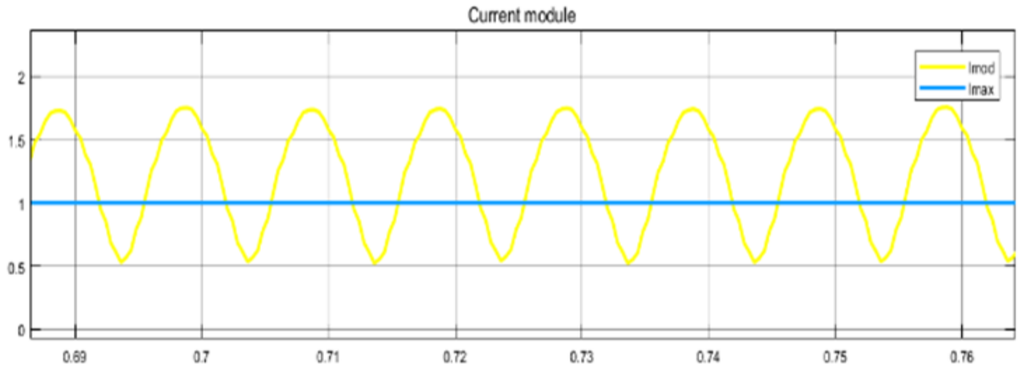
DC/DC control design

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

Contributions in control design

Negative sequence and TVI

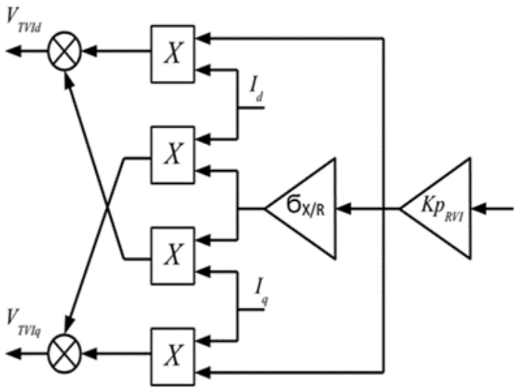


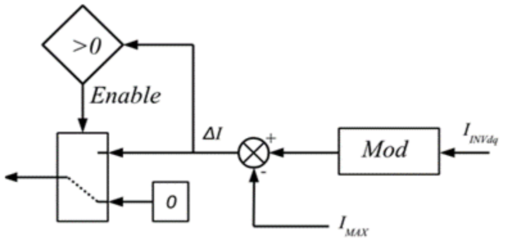


Negative Sequence at the current module is seen as a 100Hz oscillation

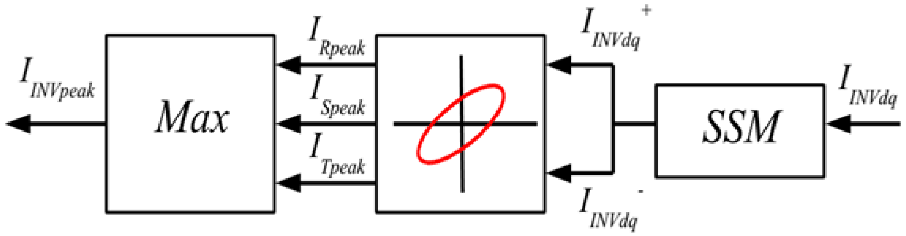
Contributions in control design

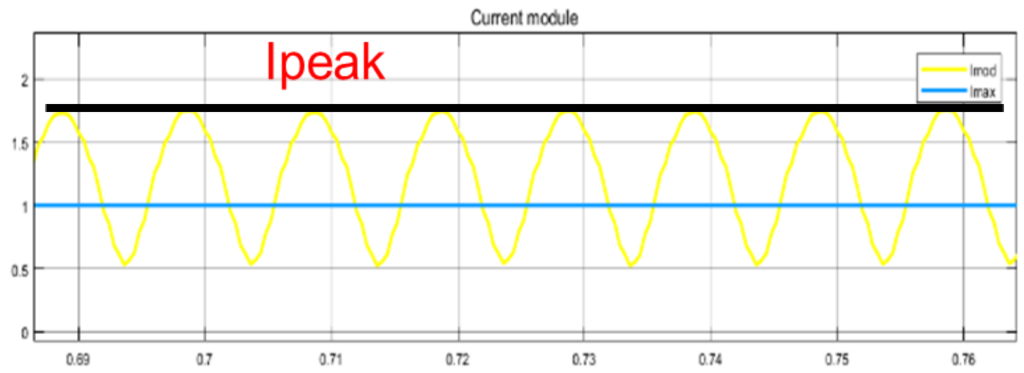
Negative sequence and TVI





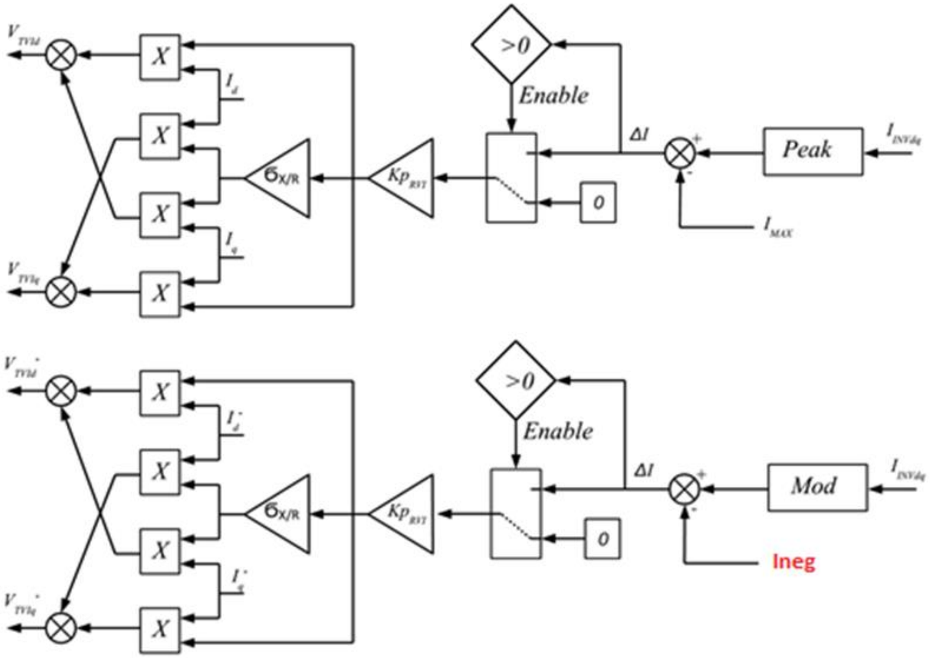
Estimation of a Ipeak value (constant)





Contributions in control design

Negative sequence and TVI

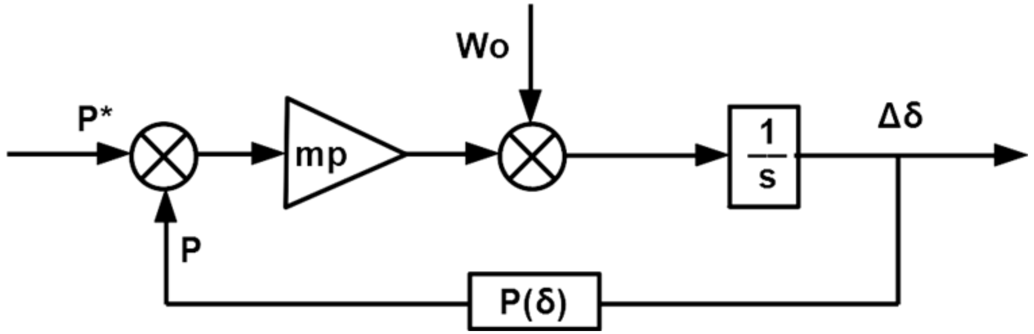


- Negative sequence current priority
- Different and settable thresholds

Shaping the behaviour at faults

Contributions in control design

Decoupling balancing (frequency-related) and synchronisation (inertia) services

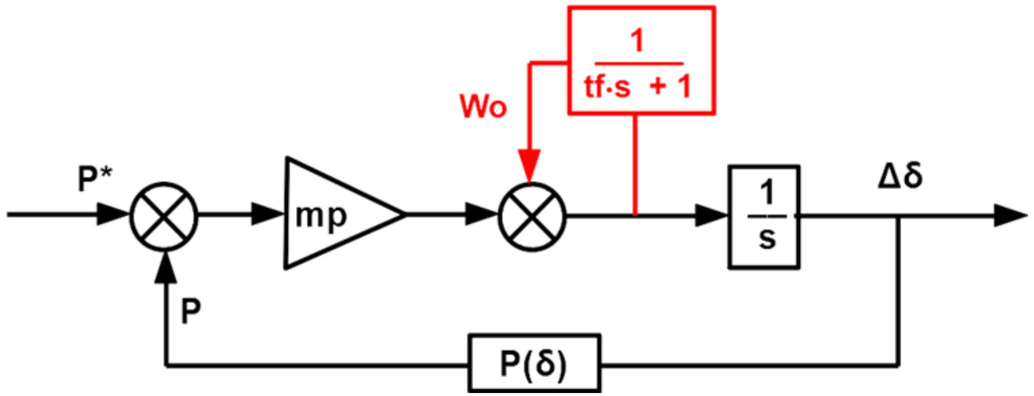


P – F droop control

$$W = (P^* - P)\, mp + Wo$$

Contributions in control design

Decoupling balancing (frequency-related) and synchronisation (inertia) services



Transient P – F droop

Inertial response at grid angle/frequency changes

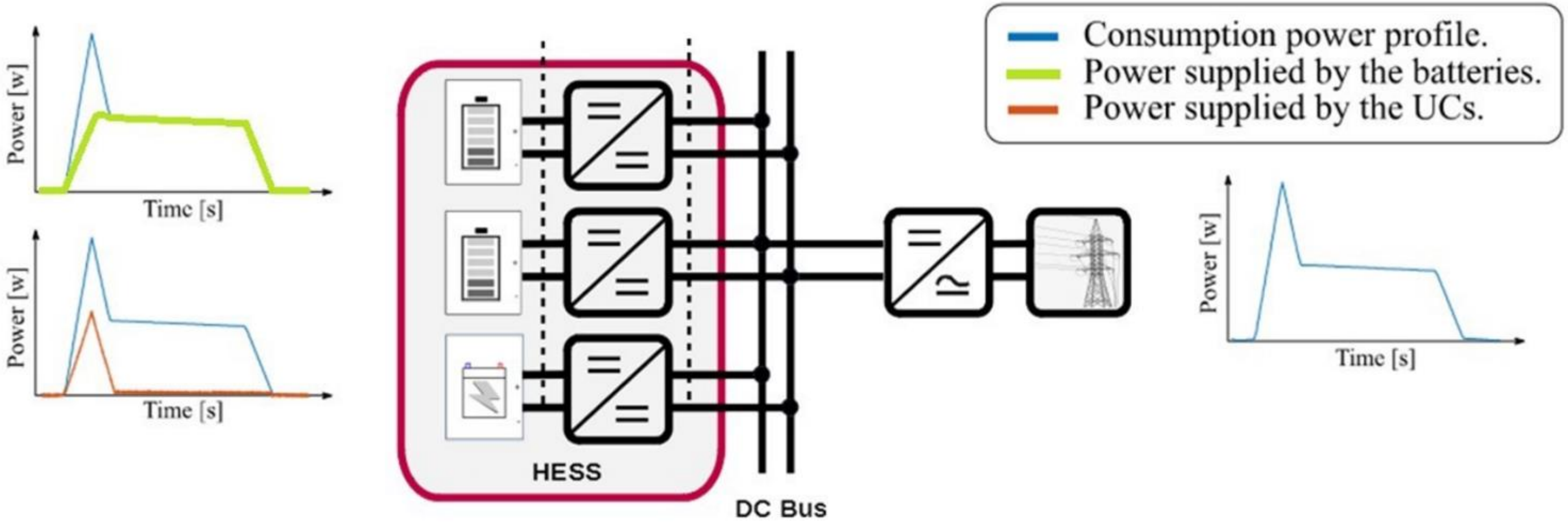
No frequency control

- Inertia constant affected by the filtering constant (both have to be in accordance)
- After 2 tf the internal frequency and grid frequency are practically the same

Contributions in control design

Decoupling balancing (energy intensive) and synchronisation (power intensive) services at device level

A micro grid is created at the DC side



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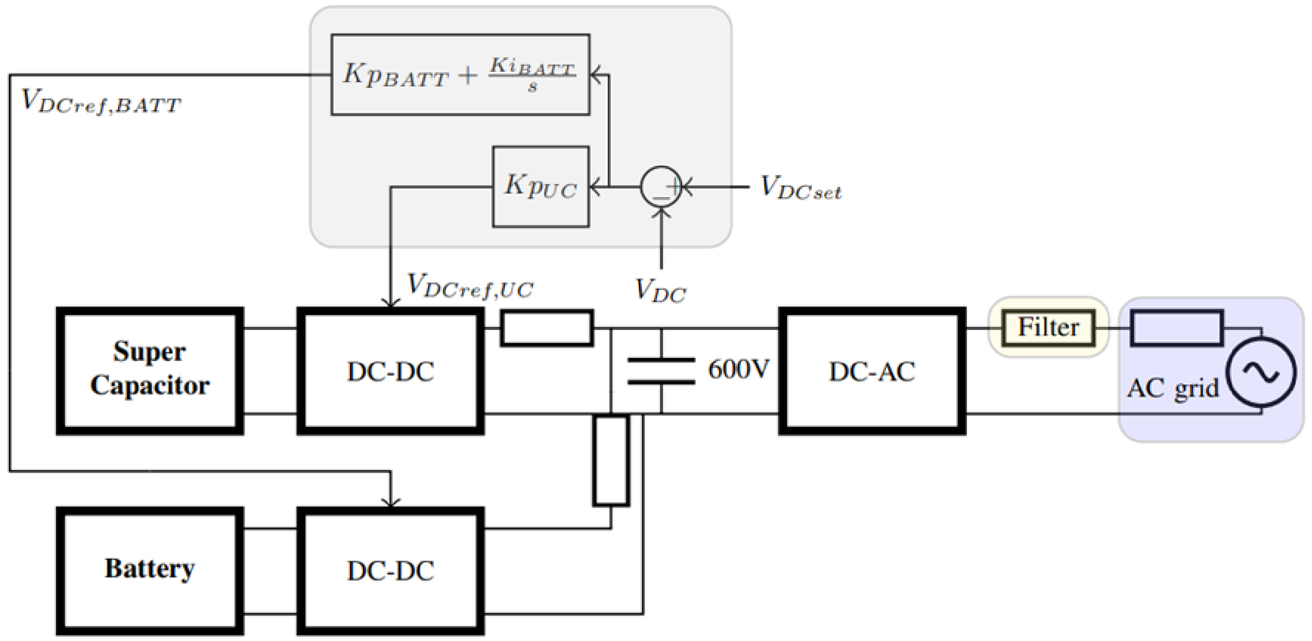
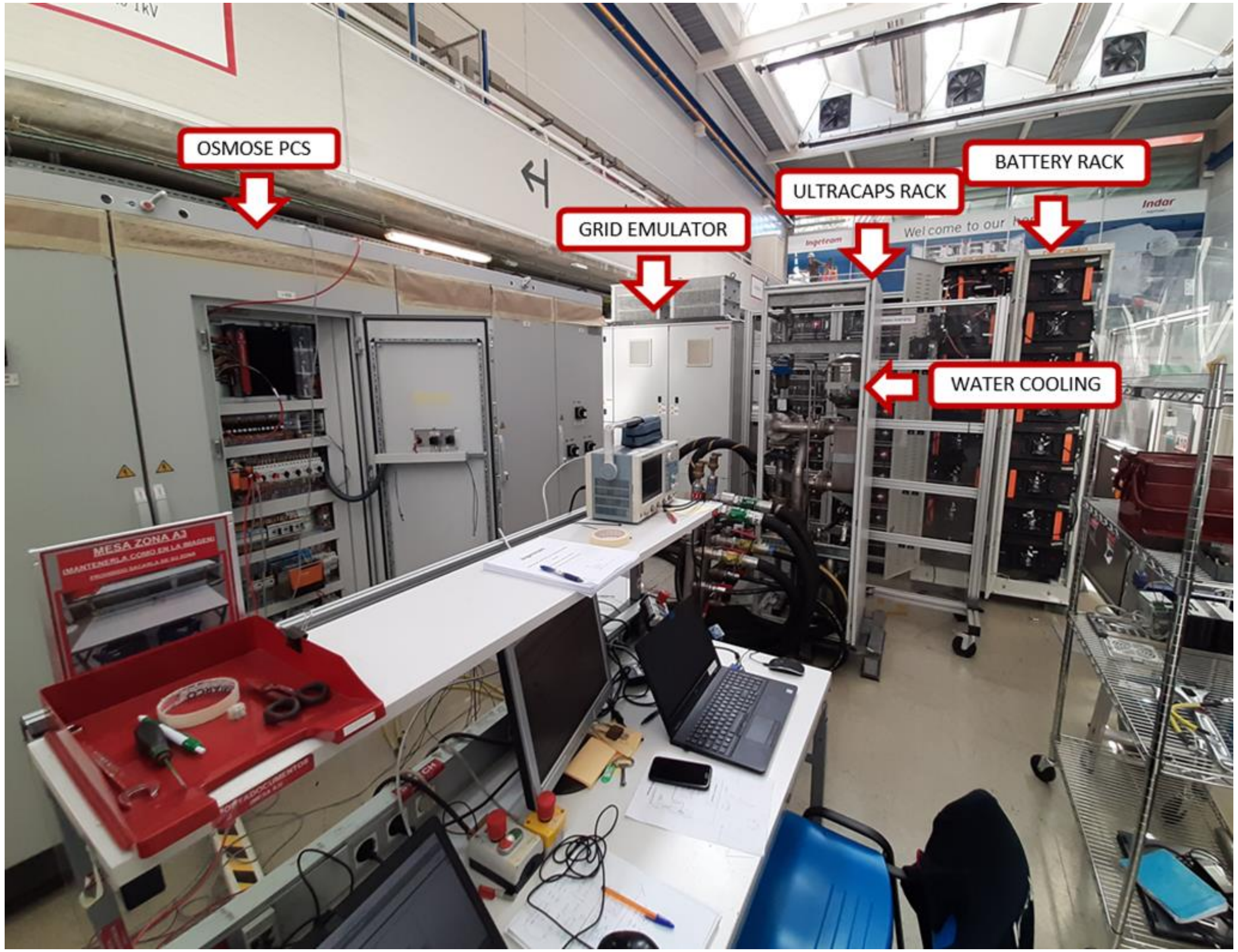


Fast DC voltage regulation is implemented for super caps

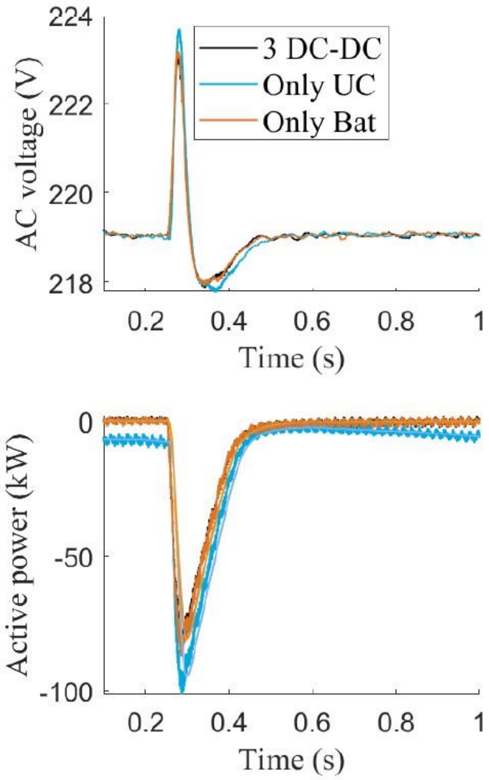
Slow DC voltage regulation for the battery

Power hardware in the loop Factory Acceptance Testing (PHIL-FAT)

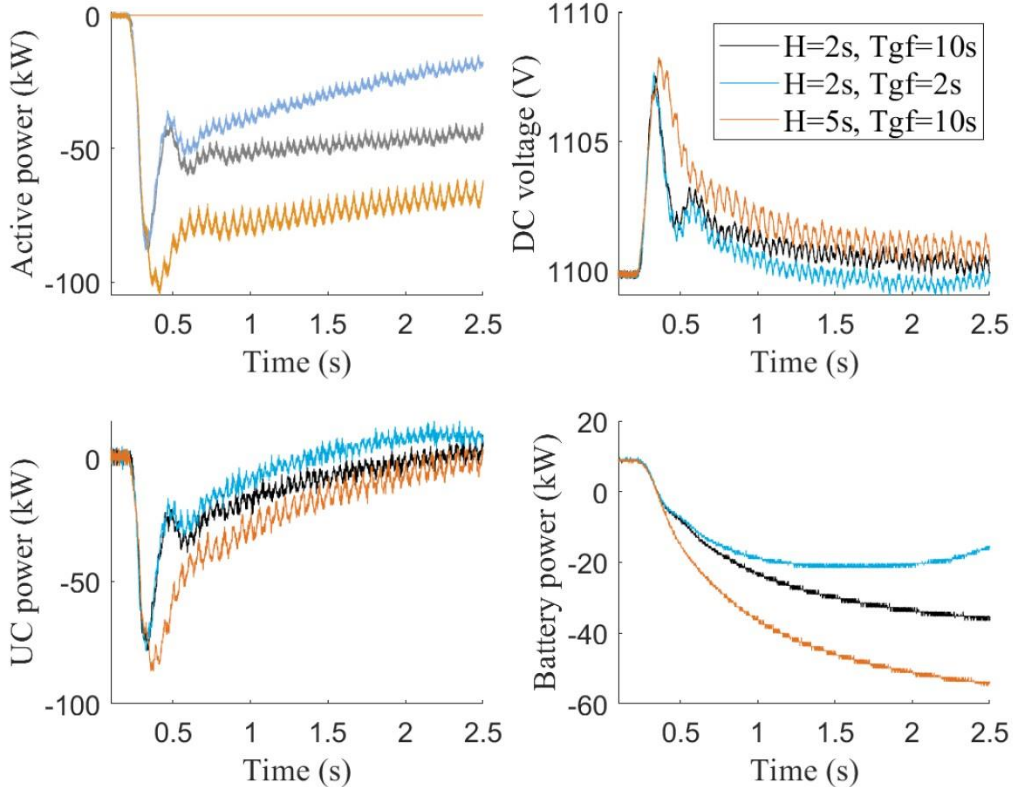


PHIL FAT results

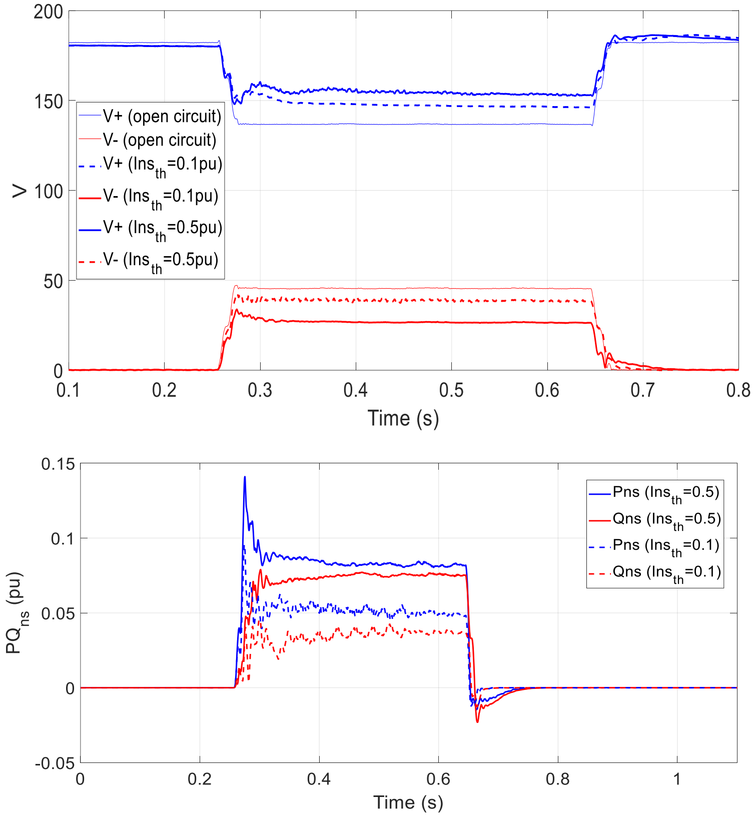
Synchronising power



Inertial response



Unbalanced fault



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- Conclusion & key take-away

EPFL Demonstrations - Outline

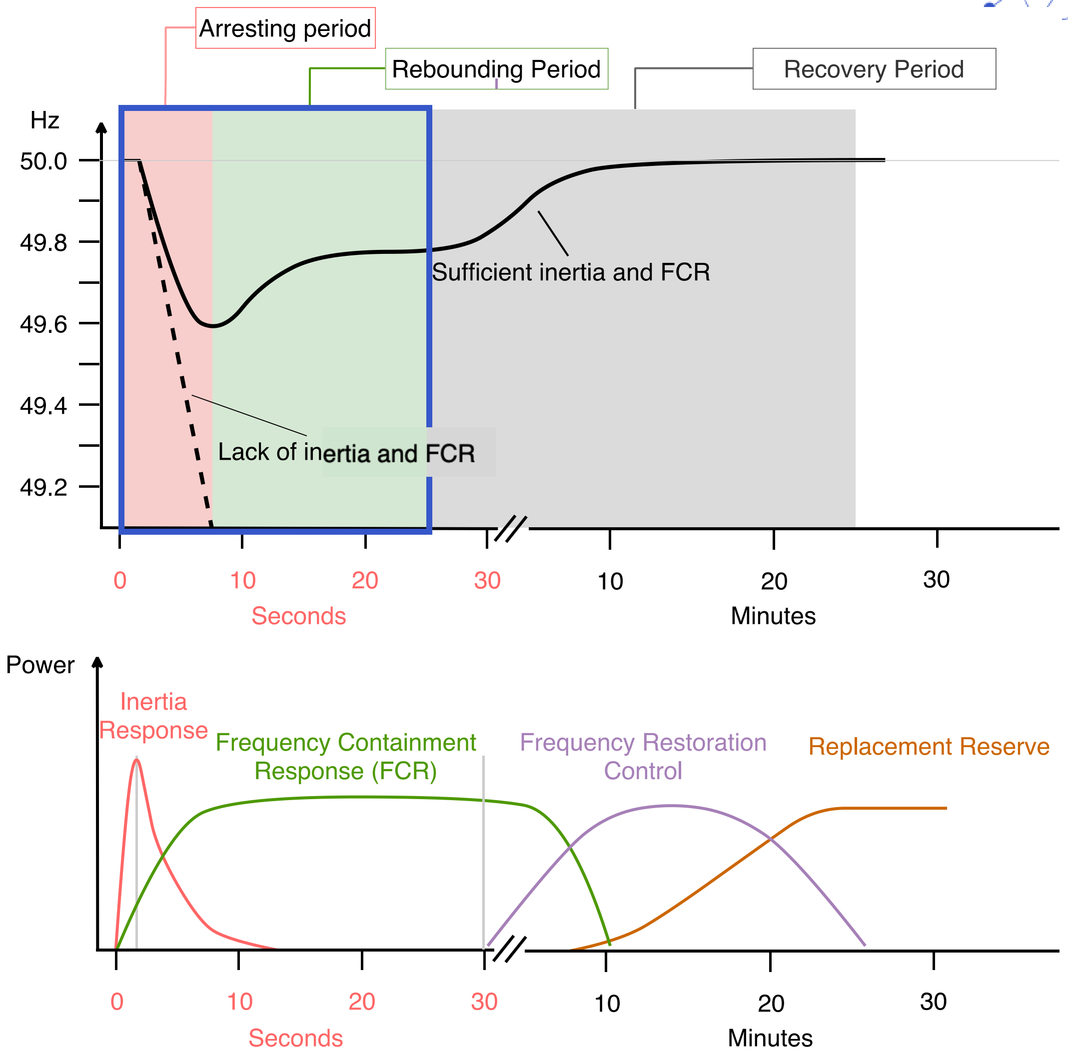
- Description of the control framework
- Description of the experimental setup
- Performance assessment of grid-forming vs grid following units in the EPFL demonstrator
- Extension of the analysis to the inertia-reduced IEEE-39 bus transmission system benchmark

Motivation

Following a large disturbance, system frequency stability is strongly related to the inertia and Frequency Containment Response (FCR) and reserve.

TSOs observed the growing necessity for FCR in actual power grids due to the increasing of converter-interfaced generation.

BESSs are advocated as a potential remedy for frequency regulation in conjunction with **grid-forming control (GFM)** providing **joint inertia and frequency containment response**.



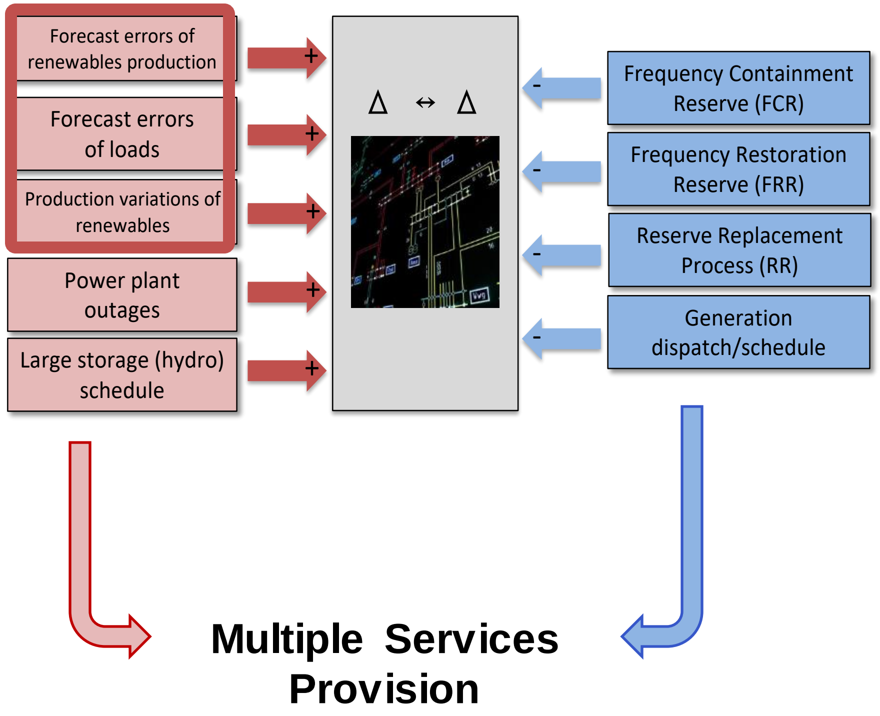
Motivation

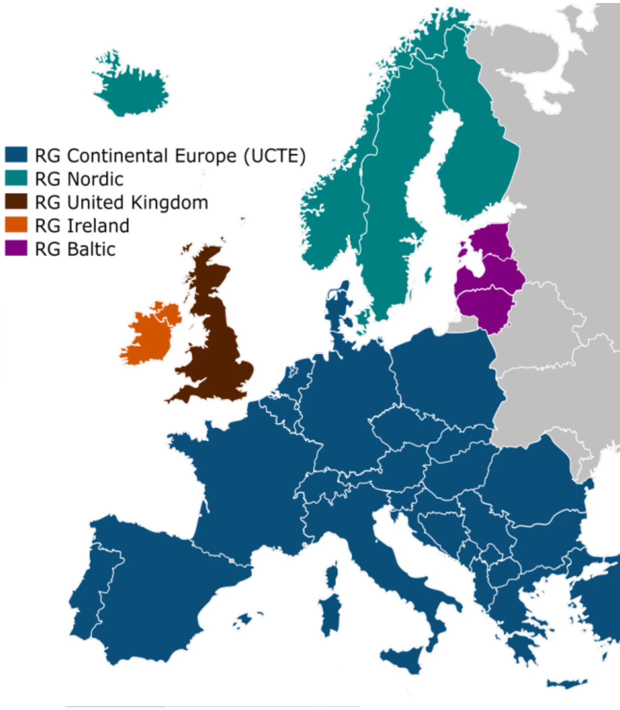
The compression of the power imbalances can be achieved by:

- Reliable **dispatch** of **stochastic resources;**
- Highly-controllable resources, e.g. **BESSs**;
- Use of suitable **controls** of power electronics.

Frequency containment problem:

- Causes of power imbalances (red)
- Control action taken to stabilize the system (blue)





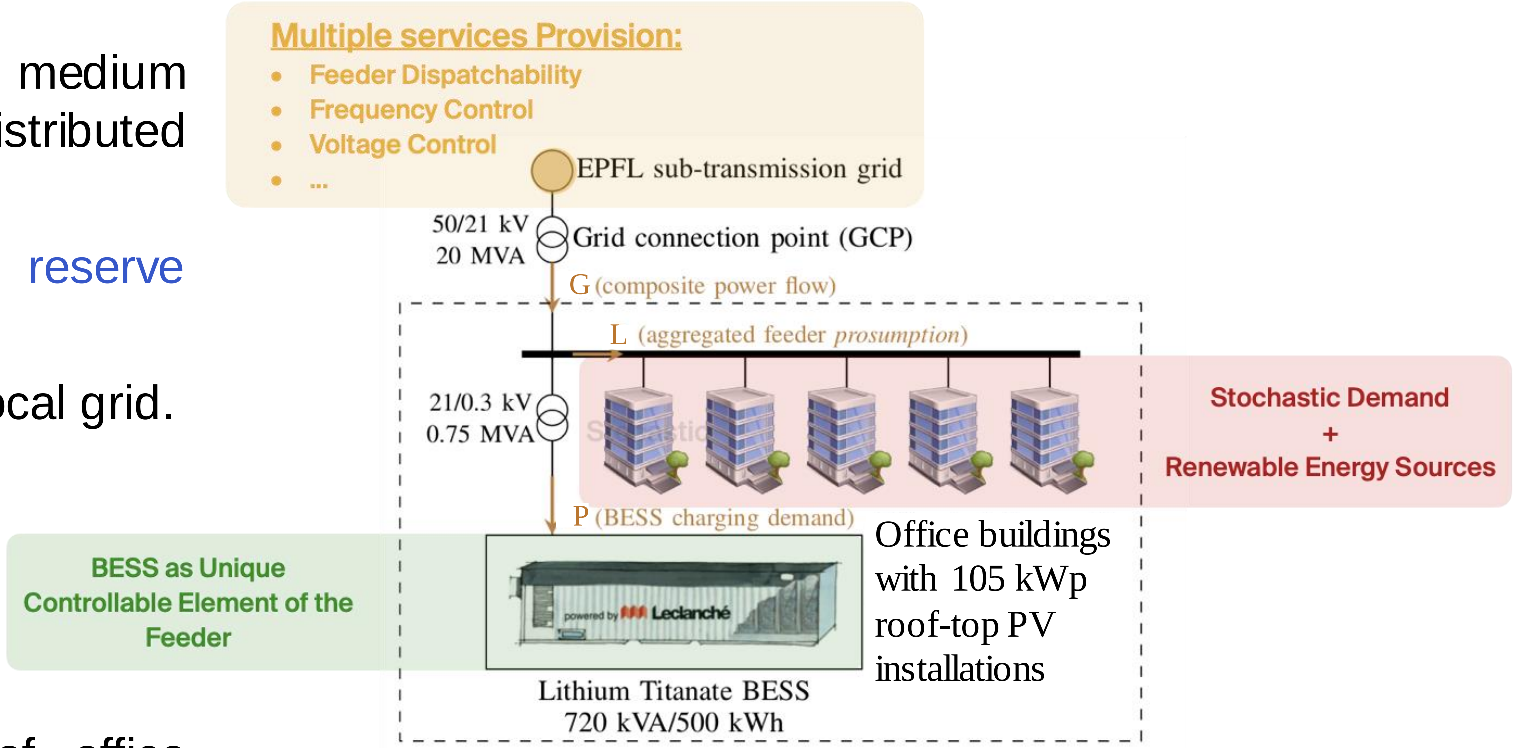
The capability of dispatching distribution networks characterized by the presence of **stochastic renewable generation** becomes of fundamental importance.

Control Framework

Objectives of the framework:

- Achieve the dispatchability of a medium voltage feeder hosting stochastic distributed generation.
- Provide frequency containment reserve (FCR).
- Provide voltage control (VC) to the local grid.
- Integrate the above functions into BESSs being the sole controllable elements of a distribution grid.

The case study presents a set of office buildings with distributed and uncontrollable PV generation.

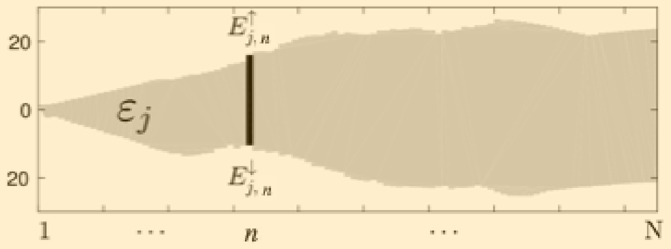


Control Framework

$$P = P_{ref} + \sigma_f \cdot (f - f_{ref})$$
$$Q = Q_{ref} + \sigma_v \cdot (v - v_{ref})$$

Day-Ahead[1]

$$[\sigma_f, \boldsymbol{F}^o] = \underset{\sigma_f, \boldsymbol{F}}{\arg\max}\ (\sigma_f)$$

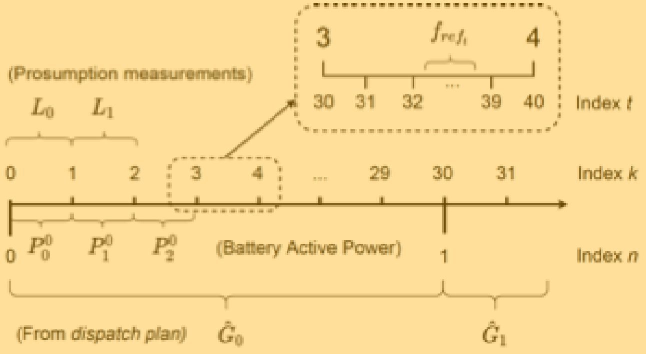


$$w\Big(\sum_j \varepsilon_{j,n}\Big) = E^{\uparrow}_{j,n} - E^{\downarrow}_{j,n} = w(\varepsilon_{dispatch} + \varepsilon_{fcr})$$
$$= \Big(\underbrace{\frac{T}{N}\sum_{i=0}^{n}(F_i + L_i^{\uparrow})}_{\varepsilon^{\uparrow}_{dispatch}} + \underbrace{\sigma_f W^{\uparrow}_{f,n}}_{\varepsilon^{\uparrow}_{fcr}}\Big) - \Big(\underbrace{\frac{T}{N}\sum_{i=0}^{n}(F_i + L_i^{\downarrow})}_{\varepsilon^{\downarrow}_{dispatch}} + \underbrace{\sigma_f W^{\downarrow}_{f,n}}_{\varepsilon^{\downarrow}_{fcr}}\Big)$$

- $F^o = F_i, \dots, F_N$ is the BESS power offset profile.
- $L = L_1, \dots L_n$ is the forecast profile of feeder prosumption.
- $\hat{G}_n = F_n + L_n$

Dispatch Tracking[2]

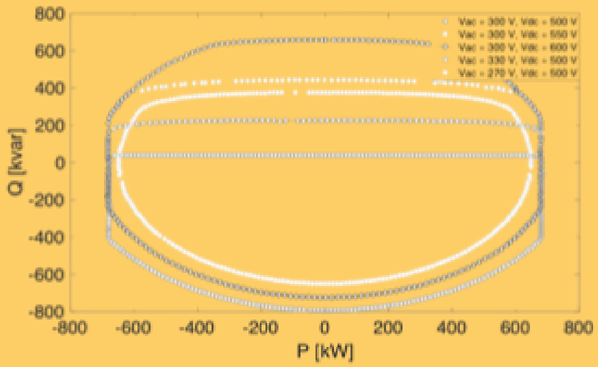
Model Predictive Control (MPC) for dispatch tracking



- $n = 0,1,2,\dots,N-1$ denotes the 5 minutes time interval for the dispatch plan and $N = 288$.
- $k = 0,1,2,\dots,K-1$ denotes the 10-seconds time interval for the MPC action and $K = 8640$.
- $t = 0,1,2,\dots,T-1$ denotes 1-second time interval for the real-time control stage and $T = 86400$.

Real Time[3]

Check capability curve



$$h(P_t, Q_t, v_t^{DC}, v_t^{AC}, SOC_t) \leq 0$$

$$f_{ref} = f_{nom} - P_{ref}/\sigma_f$$
$$V_{ref} = V_{nom} - Q_{ref}/\sigma_v$$

$$\sigma_f, \sigma_v, \hat{G}_n \quad\longrightarrow\quad P_{ref}, Q_{ref} \quad\longrightarrow\quad f_{ref}, v_{ref}$$

[1] E. Namor, "Control of Battery Storage Systems for the Simultaneous Provision of Multiple Services," in IEEE Transactions on Smart Grid

[2] F. Sossan, "Achieving the Dispatchability of Distribution Feeders Through Prosumers Data Driven Forecasting and Model Predictive Control of Electrochemical Storage," in *IEEE Transactions on Sustainable Energy*

[3] Real-Time Control of Battery Energy Storage Systems to Provide Ancillary Services Considering Voltage-Dependent Capability of DC-AC Converters in IEEE Transaction on Smart Grids

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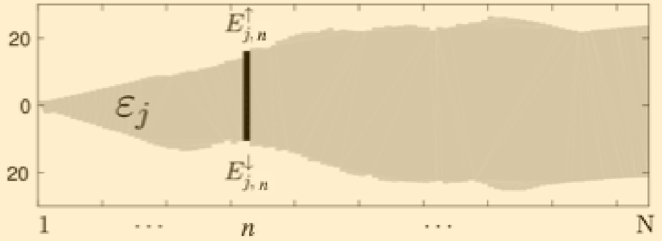

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$$\boldsymbol{\sigma_f, \sigma_v, \hat{G}_n}$$

[1]E. Namor, "Control of Battery Storage Systems for the Simultaneous Provision of Multiple Services," in IEEE Transactions on Smart Grid

Day Ahead Stage:

- Forecast of load and PV production: L.
- Computation of a dispatch plan $\hat{G}$ by estimating the amount of amount of energy and power (F) required by the BESS to track the dispatch for all scenarios.

If the nominal energy of the BESS is larger than the energy needed to achieve the dispatchability, then

- allocate the maximum possible FCR provision by determining the frequency droop σ_f.

Control Framework

$$P = P_{ref} + \sigma_f \cdot (f - f_{ref})$$
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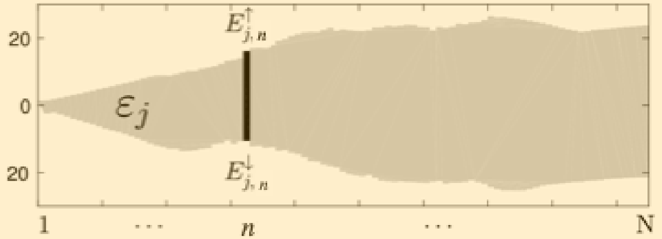

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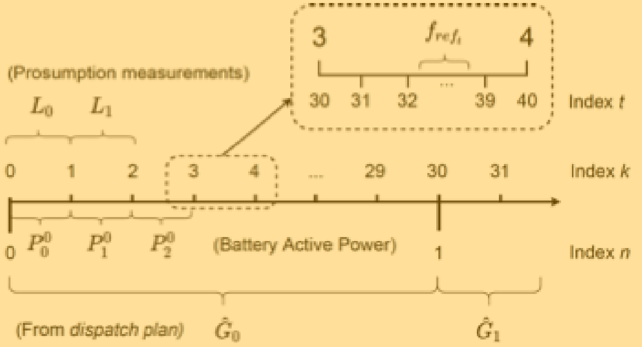
Dispatch Tracking[2]

Model Predictive Control (MPC) for dispatch tracking



- $n = 0,1,2,\ldots,N-1$ denotes the 5 minutes time interval for the dispatch plan and $N = 288$.
- $k = 0,1,2,\ldots,K-1$ denotes the 10-seconds time interval for the MPC action and $K = 8640$.
- $t = 0,1,2,\ldots,T-1$ denotes 1-second time interval for the real-time control stage and $T = 86400$.

$$P_{ref}, Q_{ref}$$

[2] F. Sossan, "Achieving the Dispatchability of Distribution Feeders Througl Prosumers Data Driven Forecasting and Model Predictive Control of Electrochemical Storage," in *IEEE Transactions on Sustainable Energy*

Intra-Day Stage (each 10 sec):

Dispatch plan tracking by means of a Model Predictive Control (MPC) algorithm relying on:

- short term prediction of the aggregated feeder presumption (load and PV);
- BESS circuit model.

Control Framework

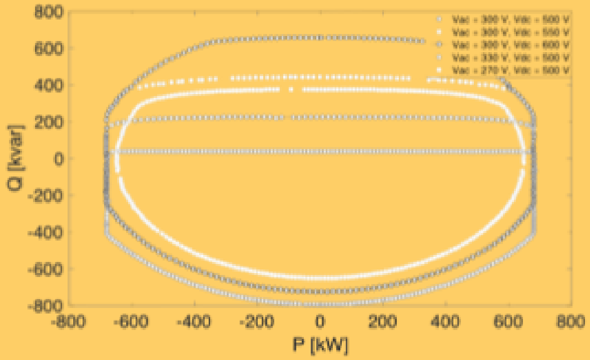
$$P = P_{ref} + \sigma_f \cdot (f - f_{ref})$$
$$Q = Q_{ref} + \sigma_v \cdot (v - v_{ref})$$

Real-time stage:

- The setpoint is converted into a frequency setpoint to feed the grid forming control of the BESS converter.
- An optimization problem is solved to ensure the operation of the BESS within the capability curves of its converter, considered their dependency on:
  - BESS State-Of-Charge (SOC);
  - AC Grid Voltage;
  - voltage of the DC bus;
  - active power;
  - reactive power.

Real Time[3]

Check capability curve



$$h(P_t, Q_t, v_t^{DC}, v_t^{AC}, SOC_t) \leq 0$$

$$f_{ref} = f_{nom} - P_{ref} / \sigma_f$$
$$V_{ref} = V_{nom} - Q_{ref} / \sigma_v$$

f_{ref} , v_{ref}

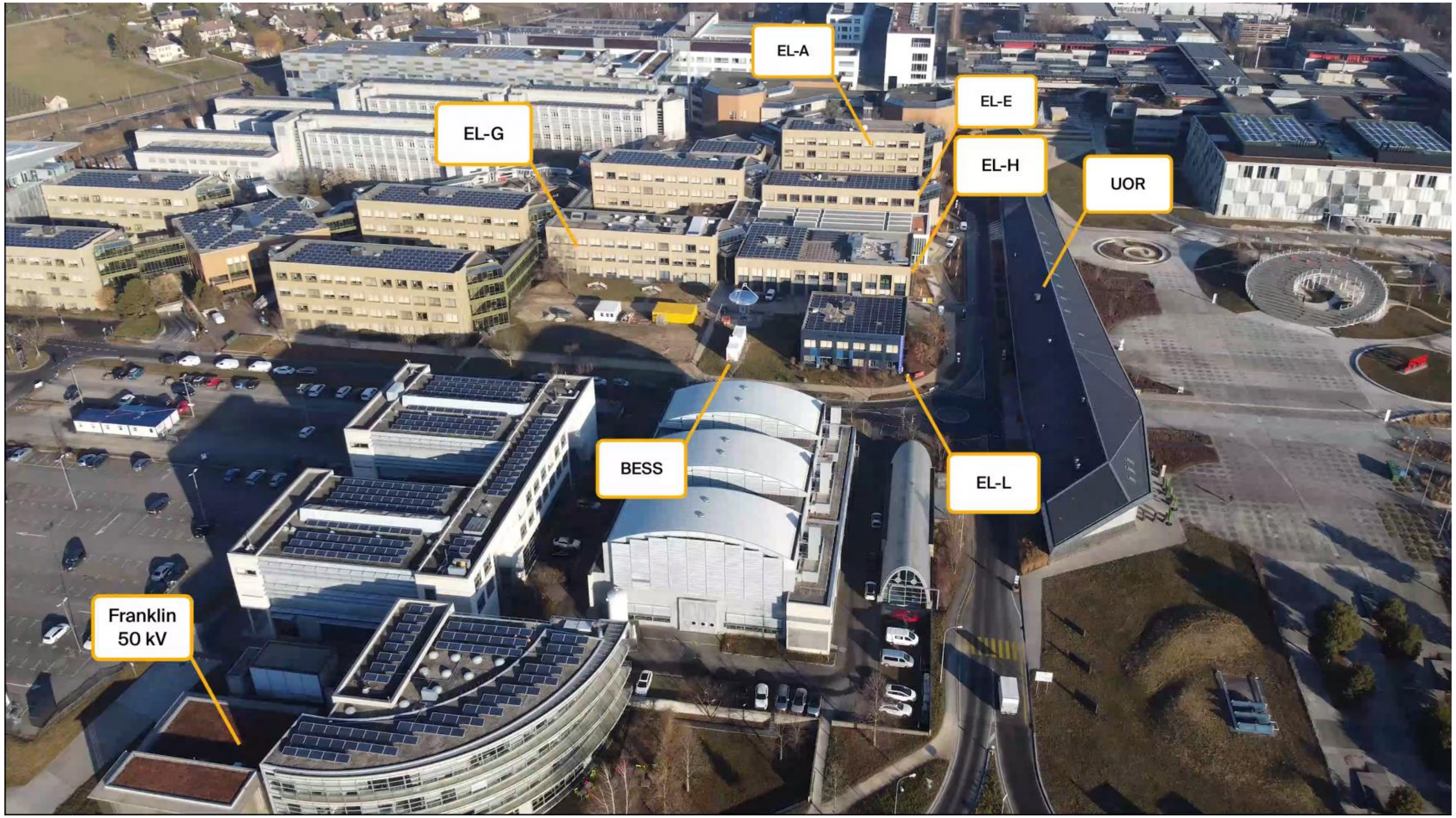
[3] Real-Time Control of Battery Energy Storage Systems to Provide Ancillary Services Considering Voltage-Dependent Capability of DC-AC Converters in IEEE Transaction on Smart Grids

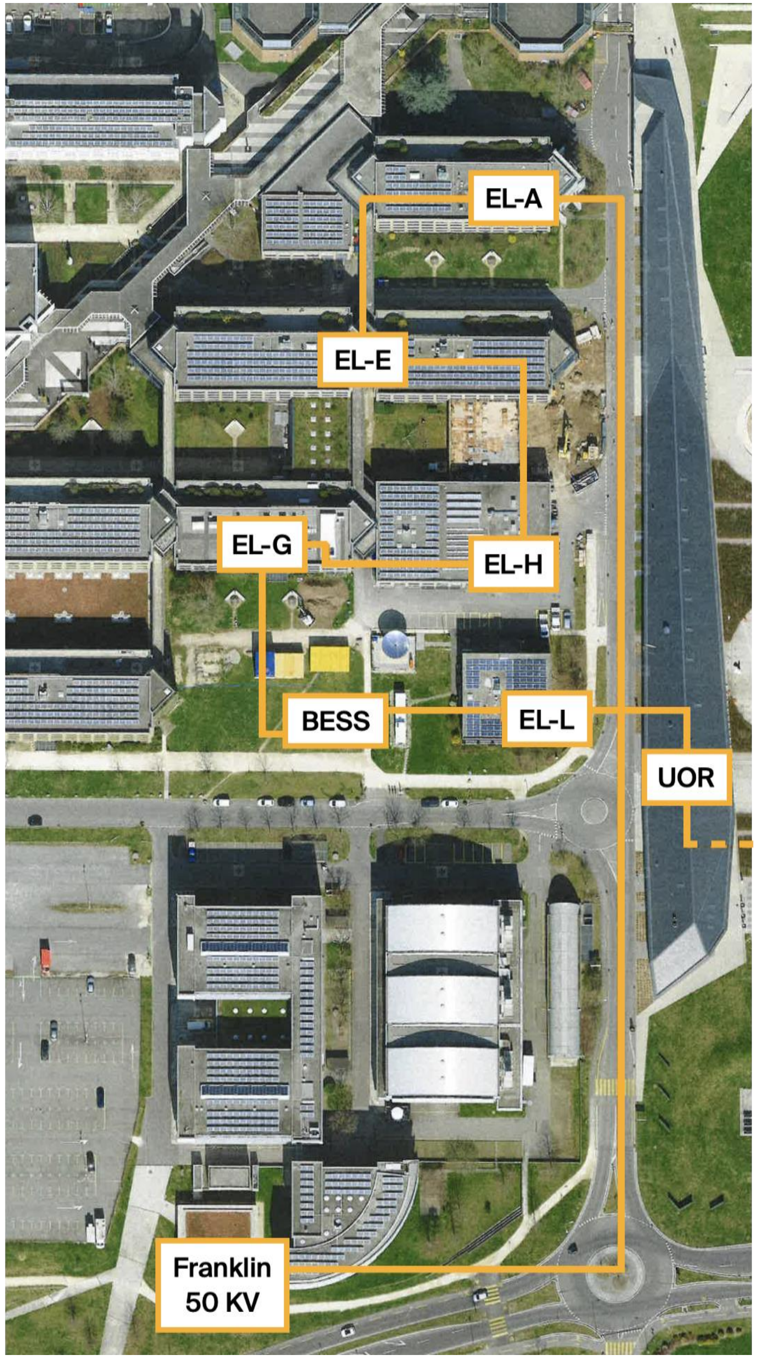
EPFL Demonstrations - Outline

- Description of the control framework
- Description of the experimental setup
- Performance assessment of grid-forming vs grid following units in the EPFL demonstrator
- Extension of the analysis to the inertia-reduced IEEE-39 bus transmission system benchmark

Experimental setup

MV **feeder** (21 kV) supplying part of the EPFL campus





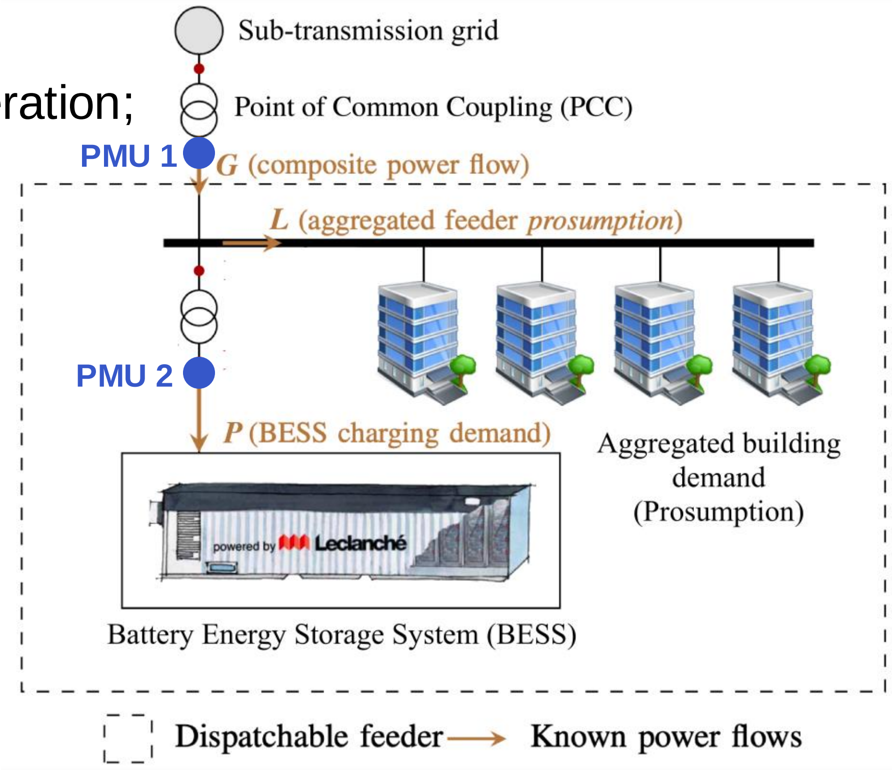
Experimental setup

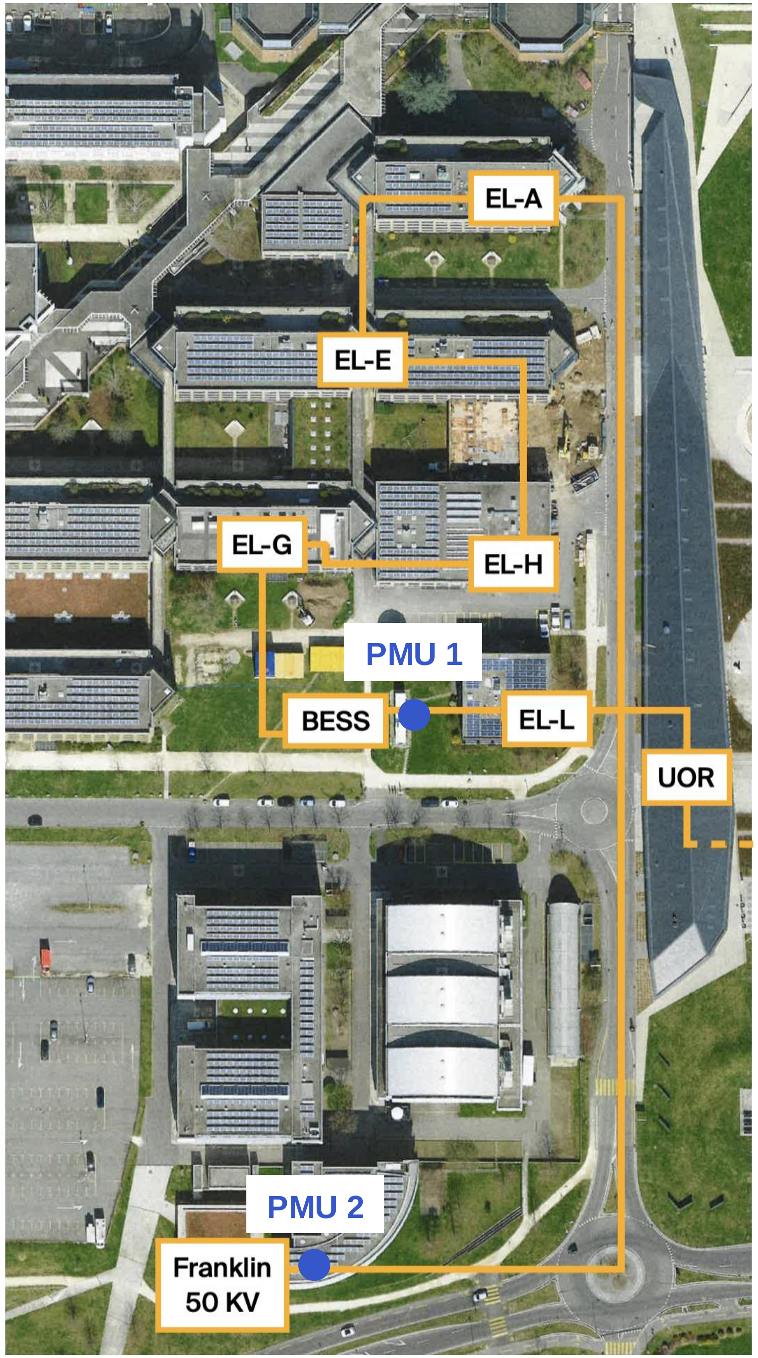
MV feeder (21 kV) supplying part of the EPFL campus characterized by:

- 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 (18 µrad).





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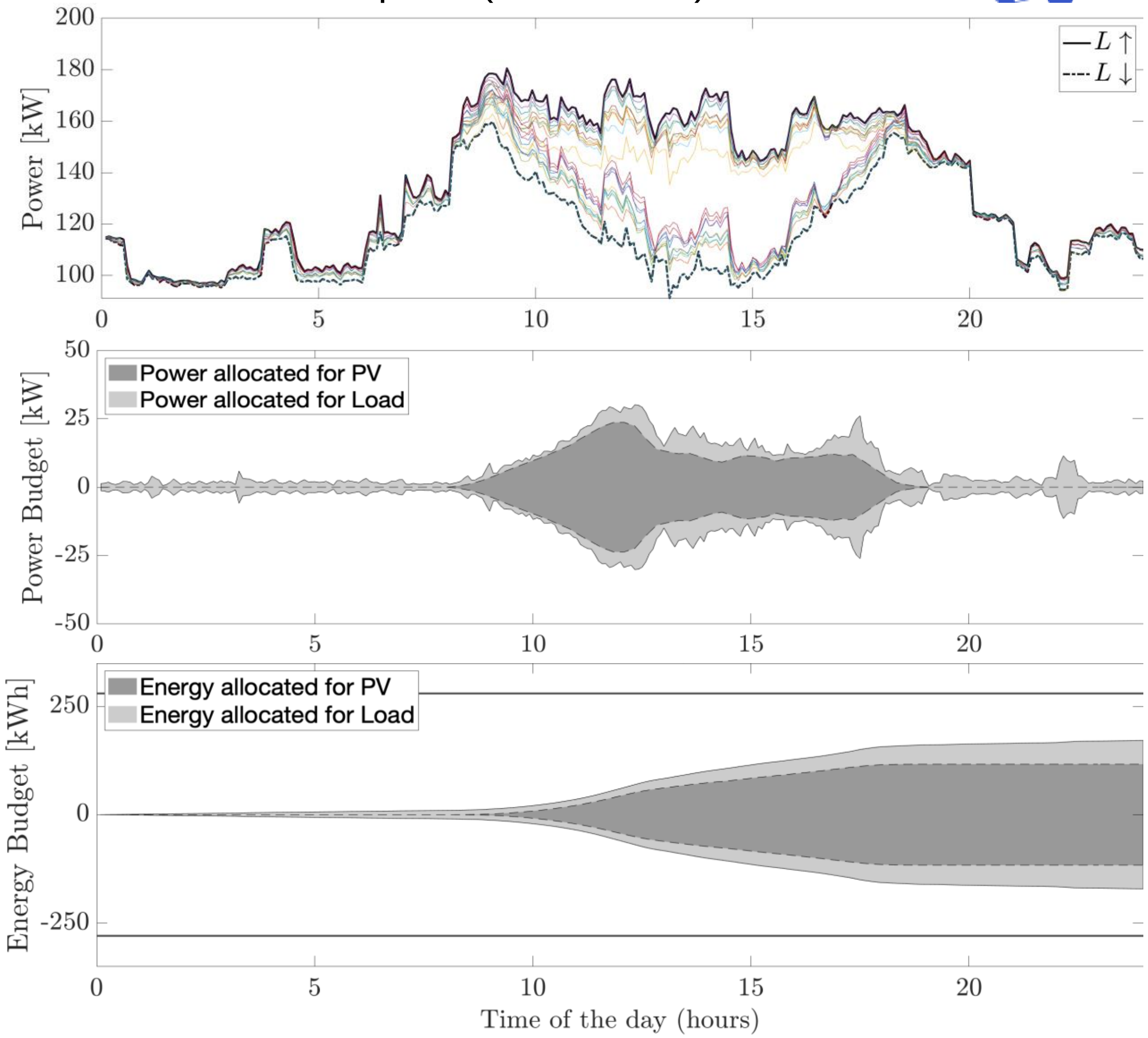
Performance assessment (Dispatch)

1. Generation of a series of **prosumption** L scenarios:
   - Disaggregation of PV and load.
   - Forecasts from meteo services.
   - Load forecasting based on historical data.

2. BESS power and energy budgets are allocated to compensate the forecasting uncertainty of **stochastic PV production** and demand.

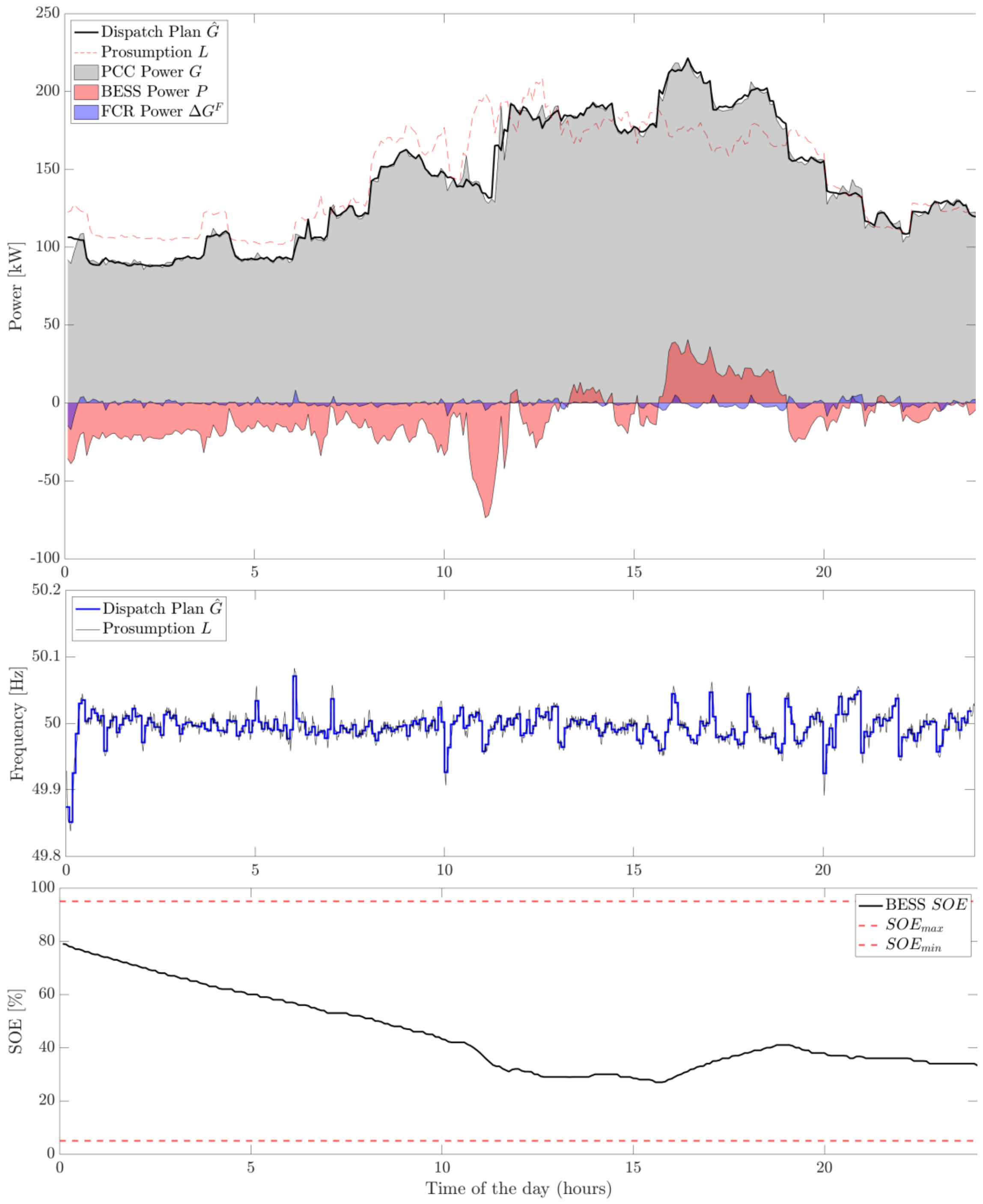
3. The **remaining BESS energy budget** is allocated for the FCR service (resulting in a droop of $\sigma_f = 116$ kW/Hz).

Prosumption (net demand) scenarios



Performance assessment (Dispatch)

- The BESS converter (controlled either as grid-forming or grid-following) corrects the prosumption (dashed **red**) such that the PCC power (in shaded **grey**) is tracking the dispatch plan (in **black**).
- The deviation of the PCC power from the dispatch plan is the result of BESS providing FCR service.
- The BESS SOC is well kept within its physical limits all over the day (as well as other constrained variables not shown here).
- The **dispatch plan is reliably tracked** and the **FCR service is provided on top of it**.



Performance assessment (FCR provision)

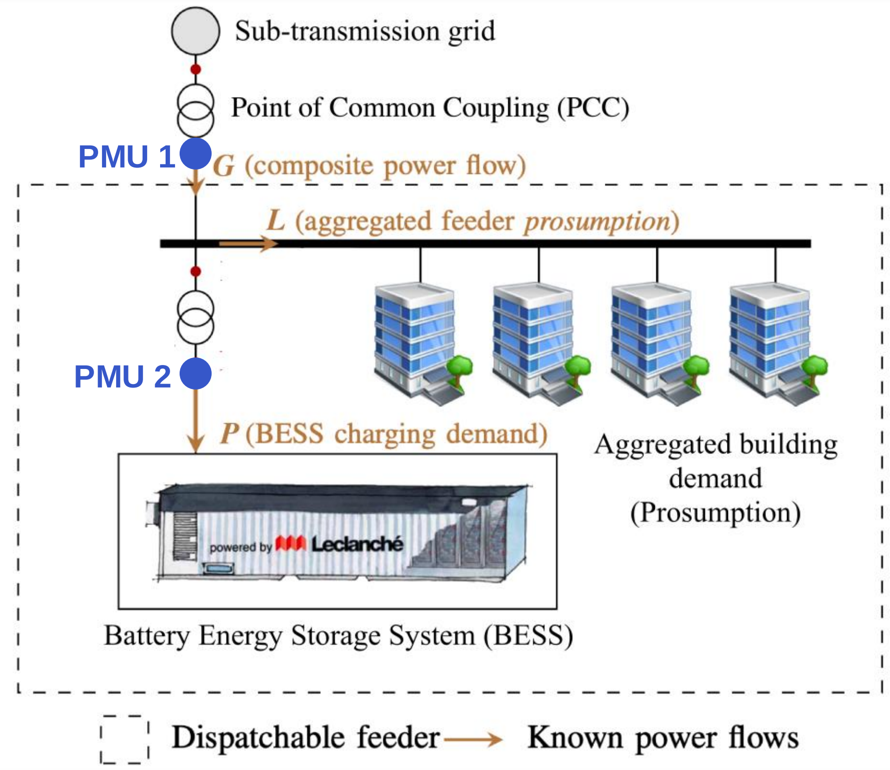
Post-process analysis of the local grid frequency associated to **Grid-forming** and **Grid-following** experimental sessions.

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

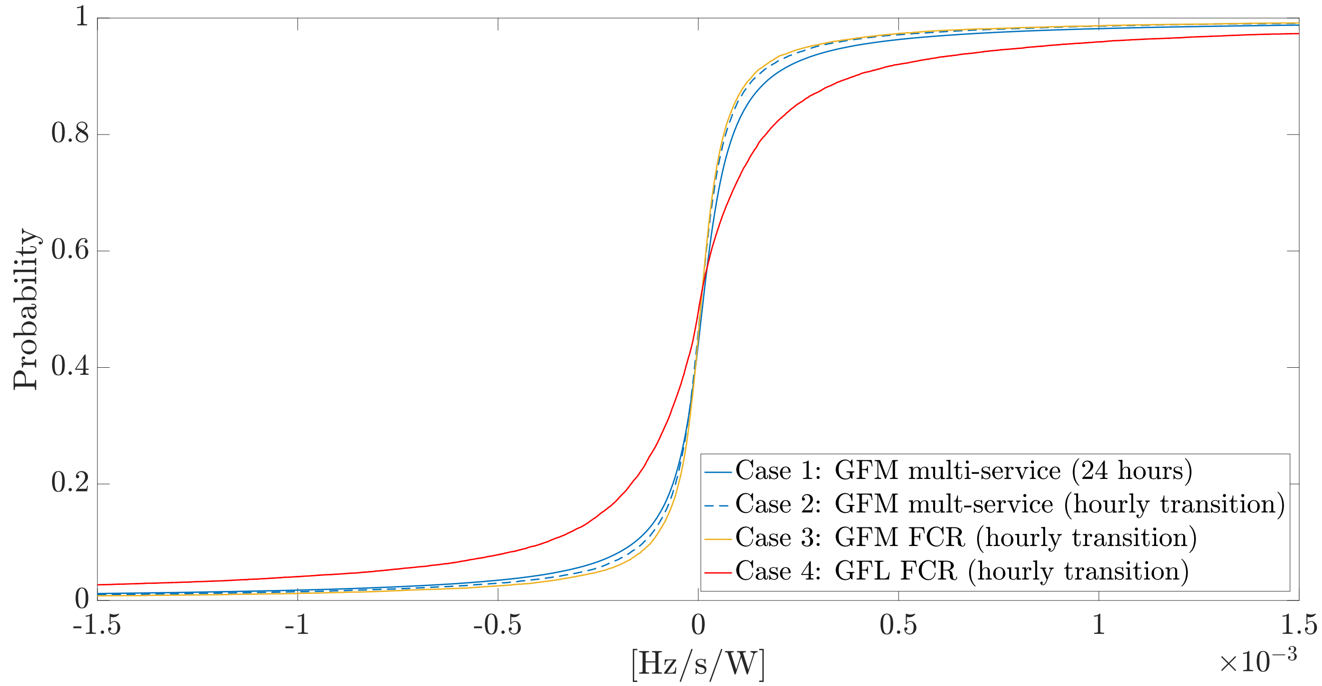
$$rRoCoF = \left| \frac{\Delta f_{pcc}/\Delta t}{\Delta P_{BESS}} \right|$$

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.



Cumulative Density Function (CDF) of the rRoCoF metric



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).

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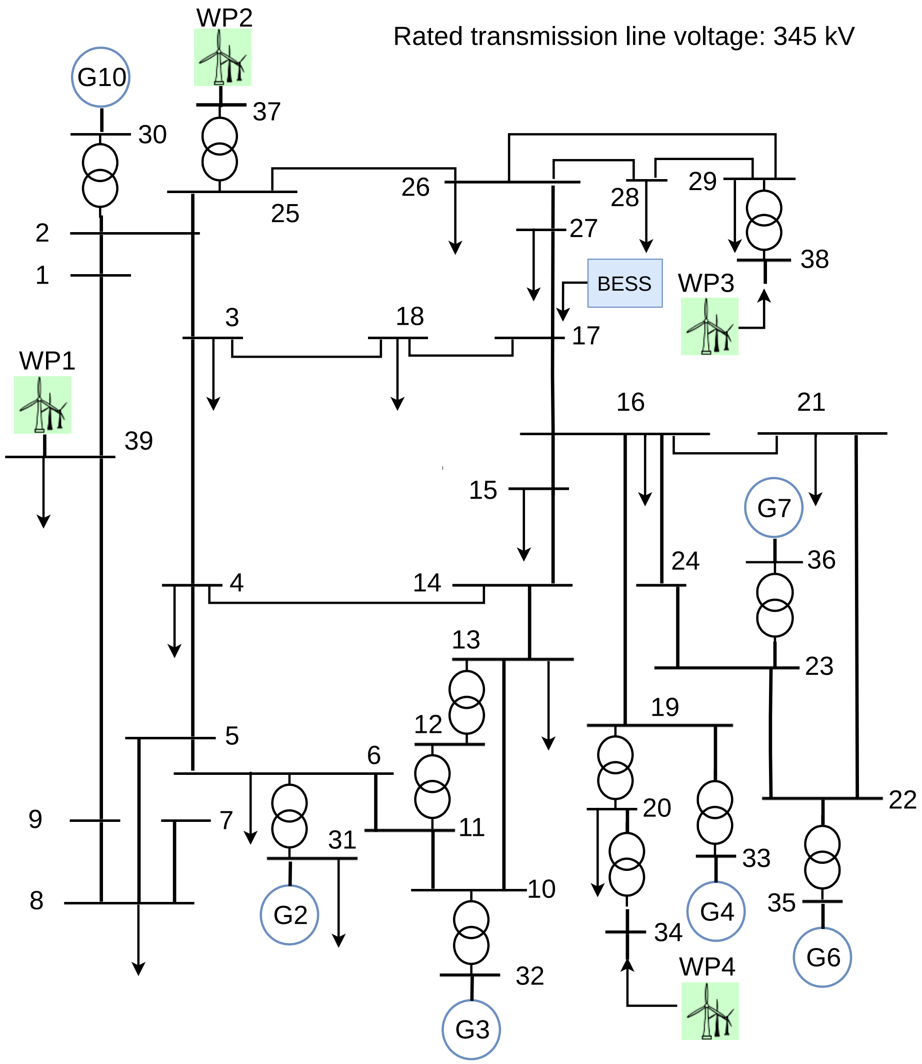
Low-inertia IEEE 39 bus simulation



- 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.

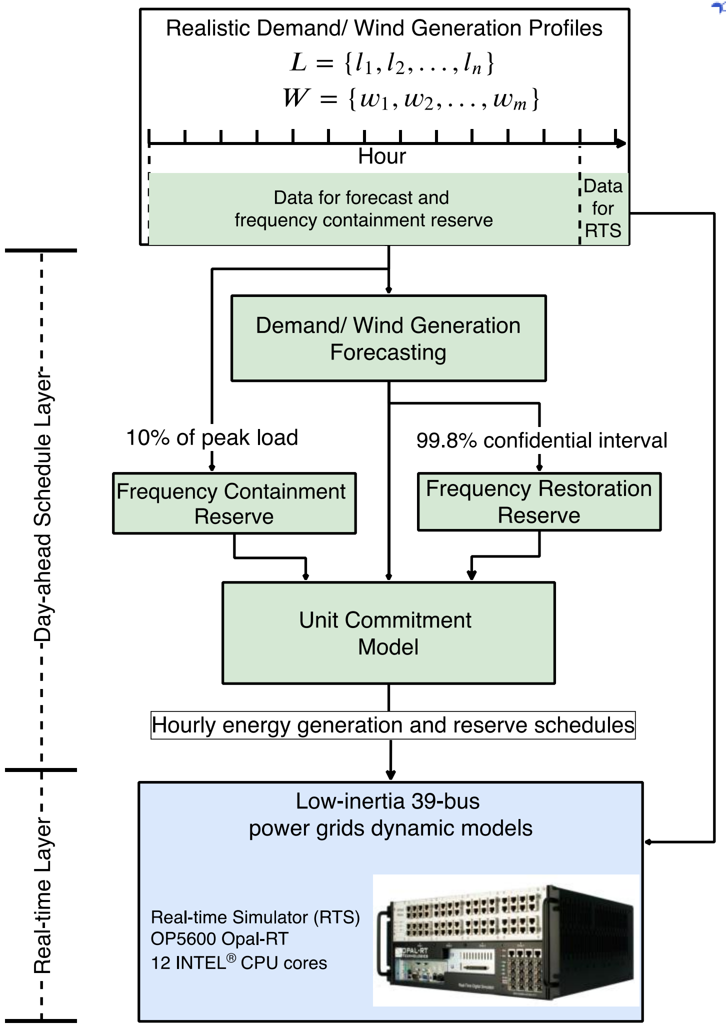
Low-inertia IEEE-39 bus simulation

Day-ahead schedule layer

- Demand and wind generation forecast.
- Frequency containment and restoration reserves.
- Unit commitment model.

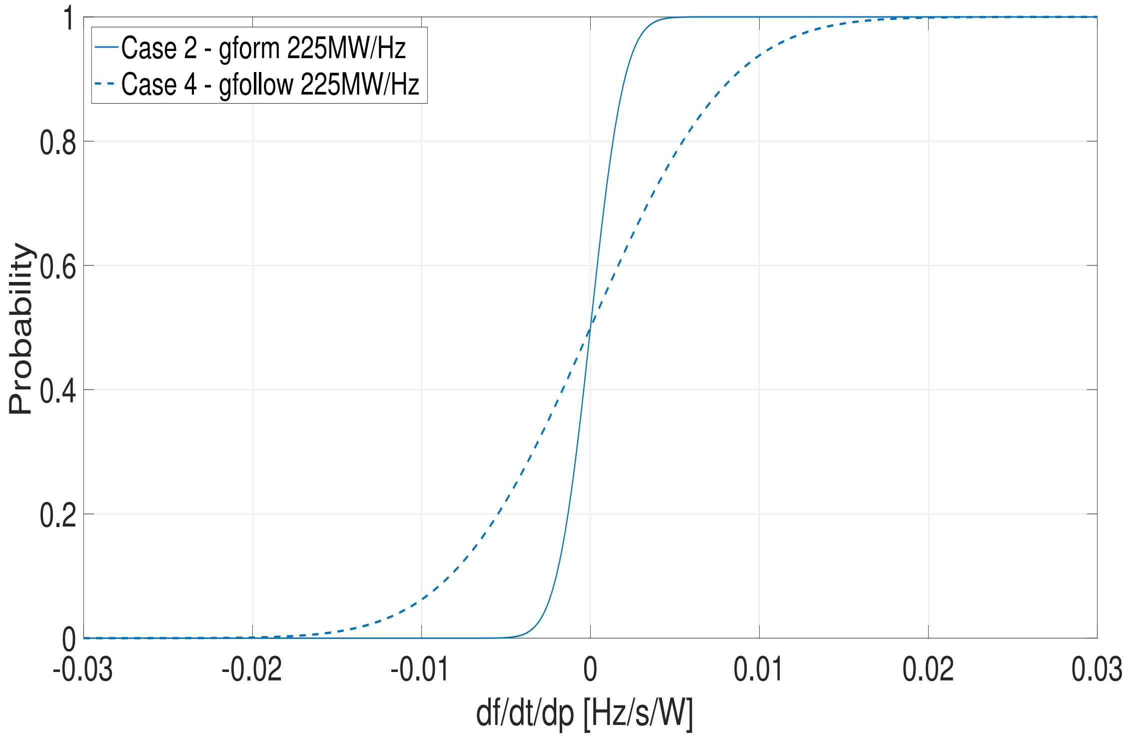
<u>Real-time Layer</u>

- **Input:** hourly energy generation and reserve schedule generated from day-ahead layer, and the realistic demand and wind generation profiles.
- Grid-forming vs grid-following converter-interfaced BESS.
- 24-hour real-time simulations of the dynamic models of low-inertia 39-bus power grids.



Results - Cumulative Density Function of rRoCoF

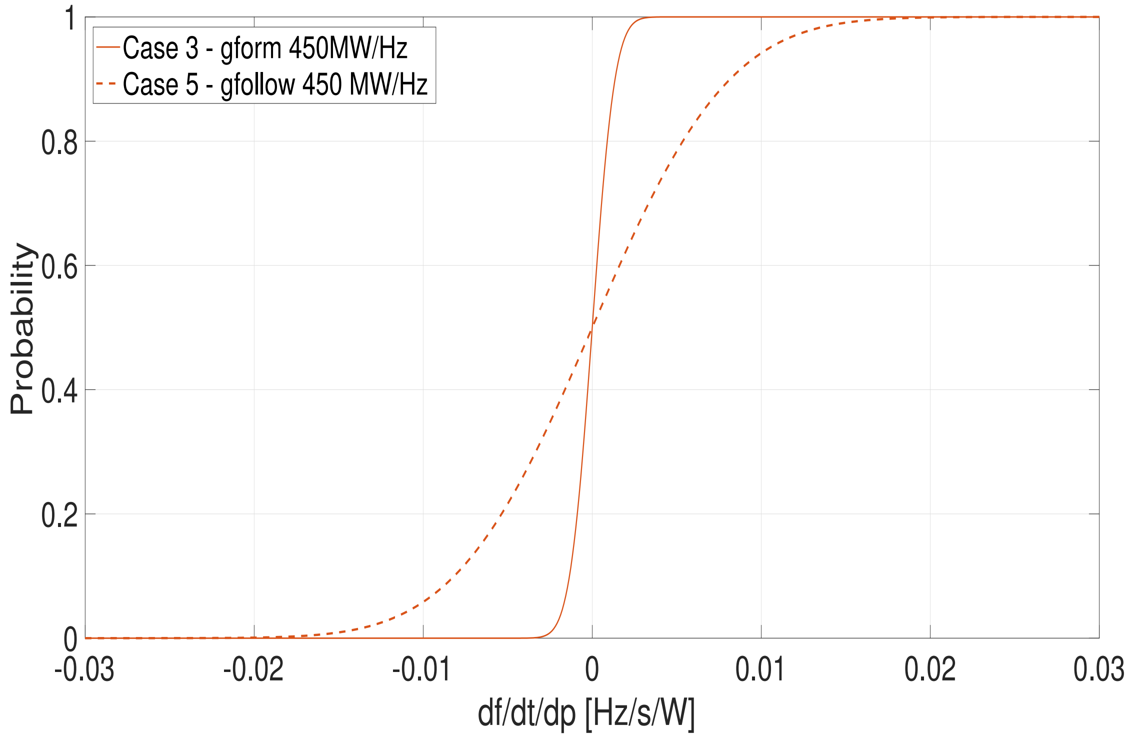
P-f droop 225 MW/Hz



Standard deviations:

- $\sigma_{case\,2}^{rRoCoF} = 0.0016$
- $\sigma_{case\,4}^{rRoCoF} = 0.0065$

P-f droop 450 MW/Hz



Standard deviations:

- $\sigma_{case\,3}^{rRoCoF} = 0.0013$
- $\sigma_{case\,5}^{rRoCoF} = 0.0064$

Conclusions on EPFL demo

- **The activity experimentally validated** the grid-forming control of BESSs providing multiple services using grid-scale 720 kVA/560 kWh BESS connected to a medium voltage feeder of the EPFL power distribution grids hosting stochastic prosumption.

- Suitably proposed metrics have quantified the superior performance of grid-forming control compared to the grid-following one.

- Scale-up assessment on the frequency performance of **low-inertia IEEE 39-bus** benchmark network demonstrates that grid-forming controlled BESS outperforms grid-following one in improving the system frequency containment.

Agenda

- Introduction to OSMOSE and demos
- Presentation of the RTE-Ingeteam demo
  - Specification of grid forming capability
  - AC/DC converter control design, grid forming controls and DC side management strategies
  - Grid forming capability compliance verification
- Presentation of the EPFL Demonstrations
  - Description of the control framework and experimental setup
  - Performance assessment of grid-forming vs grid following units in the EPFL demonstrator.
  - Extension of the analysis to the inertia-reduced IEEE 39 bus transmission system benchmark.
- **Conclusion & key take-away**

Take-away messages

- 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.

- **Experimental validation** that type 3 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 an enhanced NS-TVI and a GFM capability compliance testing procedure.

- **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).

Take-away messages

- The contribution of grid-forming BESS to the system inertia and FCR can be considered as a potential way **to counterbalance the constant increase of regulation services** due to the massive connection of renewable power generation.
- This contribution may be certified by adequate grid codes and market mechanisms taking into account the peculiarity of this technology.
- The day-ahead and intra-day dispatch of active distribution network hosting both stochastic and controllable resources needs to be regulated in view of its large potential to reduce the FCR and FRR at the bulk power system level.

Future work

- Implementation of grid connection requirements associated to **minimal GFM capability** for HVDC systems and power park modules (PPM) connected to the transmission grid. Proposal of performance checking sheets for compliance verification. Consultation process with stakeholders.

- Experimental demonstration of **different types of GFM capability** of other technologies than ESS such as PPM, HVDC and FACTS shall continue until industrial deployment is achieved.

- Assessment of system needs in order to define global and local prescription of synchronisation services.

- Original equipment manufacturers and academy can build upon public results to enhance robustness of grid forming control and real-time multi-service optimisation of energy systems.

Further reading

1. Enhanced TVI for Grid Forming VSC under Unbalanced Faults. Published on Energies. Available on: https://www.mdpi.com/1996-1073/14/19/6168

2. OSMOSE WP3: Factory Acceptance Test of the grid forming demonstrator. Presented in SIW 2020. Available on: https://www.researchgate.net/publication/348818638_OSMOSE_WP3_Factory_Acceptance_Test_of_the_grid_forming_demonstrator

3. OSMOSE Grid-Forming performance assessment within multiservice storage connected to the transmission grid. Presented in Cigre 2020. Available on: https://www.researchgate.net/publication/348818490_OSMOSE_Grid-forming_performance_assessment_within_multiservice_storage_connected_to_the_transmission_grid

4. Upgrade of a grid-connected storage solution with grid-forming function. Presented in SIW 2019. Available on: https://www.researchgate.net/publication/337561687_Upgrade_of_a_grid-connected_storage_solution_with_grid-forming_function

5. Performance assessment of Synchronous Condensers vs Voltage Source Converters providing grid-forming functions. Presented in PowerTech 2021. Available on: https://arxiv.org/abs/2106.03536

OSMOSE Final webinar series

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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*

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Webinar Q&A – Demonstration of grid forming capabilities and synchronisation services

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OSMOSE

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