International Workshop on
Dynamic Stability Challenges of the Future Power Grids

BESS Grid Forming demonstrator

Presenter
Luca Orrù, Giuseppe Lisciandrello
Terna SpA
Italy

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- Origination and objectives
- Technical Specification
- Test campaign
- Test results
- Conclusions


9th International Workshop on Dynamic Stability Challenges of the Future Power Grids
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Origination and objectives

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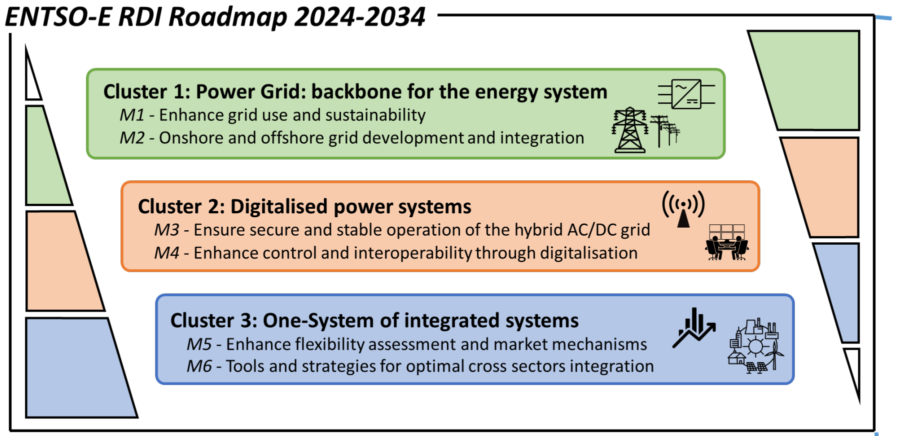
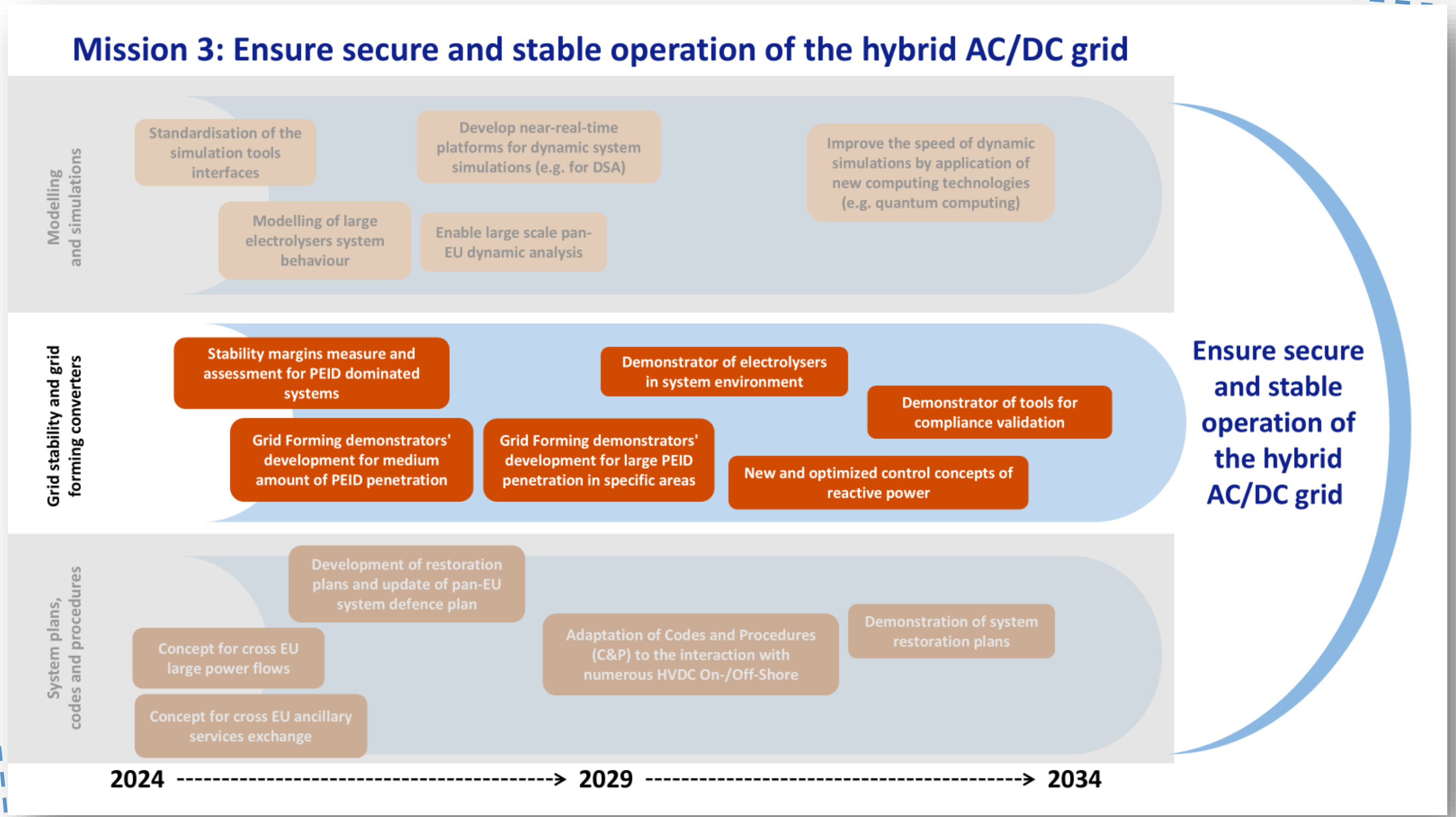


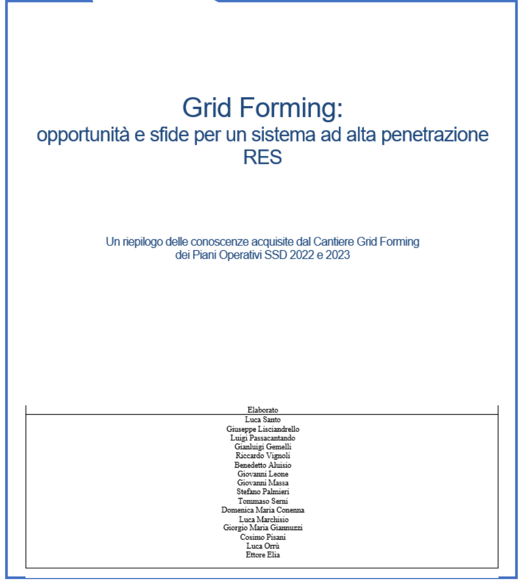
- TSOs innovation roadmaps are aligned about the **strong relevance of the stability issue in future scenarios**
- In the short-term, **stability margins of future PEID-dominated systems** need to be carefully assessed to guarantee stable system operations
- Key opportunity arises from **demonstrating and exploiting grid forming capabilities** from power converters, through a step-by-step approach



Also Terna has recently launched, over the last 5 years, **multiple initiatives aimed at exploring the potential of grid forming** and disseminating know-how internally, including **visiting to plants** and laboratories, **survey** addressed to technical and market stakeholders, internal **demonstration projects**.

The goal of the Grid Forming Demo project, in particular, is to conduct field testing activities in **Codrongianos Storage Lab** using **one of the 1 MW batteries** installed there, in order to test the performance of the technology and assess its limitations and potential in HV applications.

2022	2023	Dec '23 – Jun '24	July '24	Sep-Oct '24	Oct '24 – Mar '25
Tech specification	Procurement	Development and implementation	FAT	Installation	Test


Grid Forming:
opportunità e sfide per un sistema ad alta penetrazione RES

Un riepilogo delle conoscenze acquisite dal Cantiere Grid Forming dei Piani Operativi SSD 2022 e 2023

Elaborato
Luca Santo
Giuseppe Lisciandrello
Luigi Passacantando
Gianluigi Gemelli
Riccardo Vignoli
Benedetto Aluisio
Giovanni Leone
Giovanni Massa
Stefano Palmieri
Tommaso Serni
Domenica Maria Conenna
Luca Marchisio
Giorgio Maria Giannuzzi
Cosimo Pisani
Luca Orrù
Ettore Elia

Visiting Grid Forming in Australia

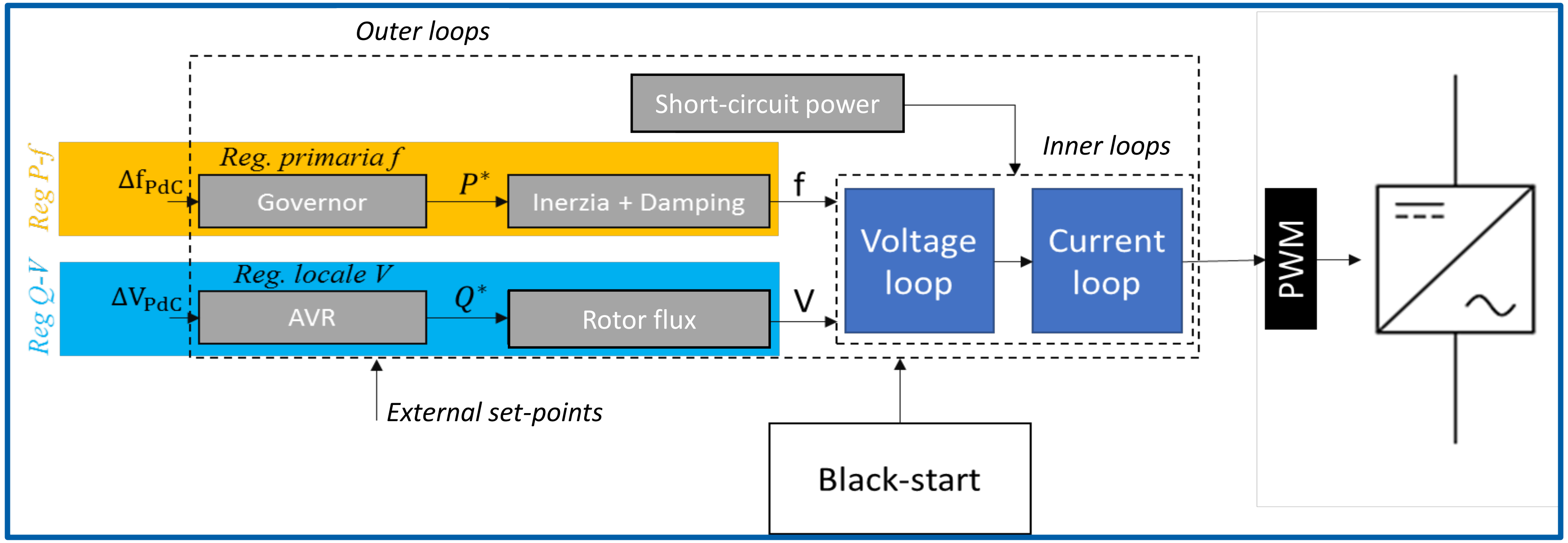
Technical Specification

*Through their advanced control logic, innovative **Grid Forming (GFM) inverters** can emulate certain behaviors of **traditional synchronous generators**, thereby enhancing the **stability of the power system**.*
GFM technology could be deployed on inverter-based plants (batteries, wind, photovoltaic) with potentially lower costs.

The control logic enables the inverter to operate as a **voltage source** with a series impedance. This is achieved through the so-called "inner loops."

For applications in interconnected grids, additional control blocks—known as "outer loops"—must be implemented. These define the GFM control strategy.

There are several GFM strategies; the one selected for the trial is the **Virtual Synchronous Generator (VSG)**.



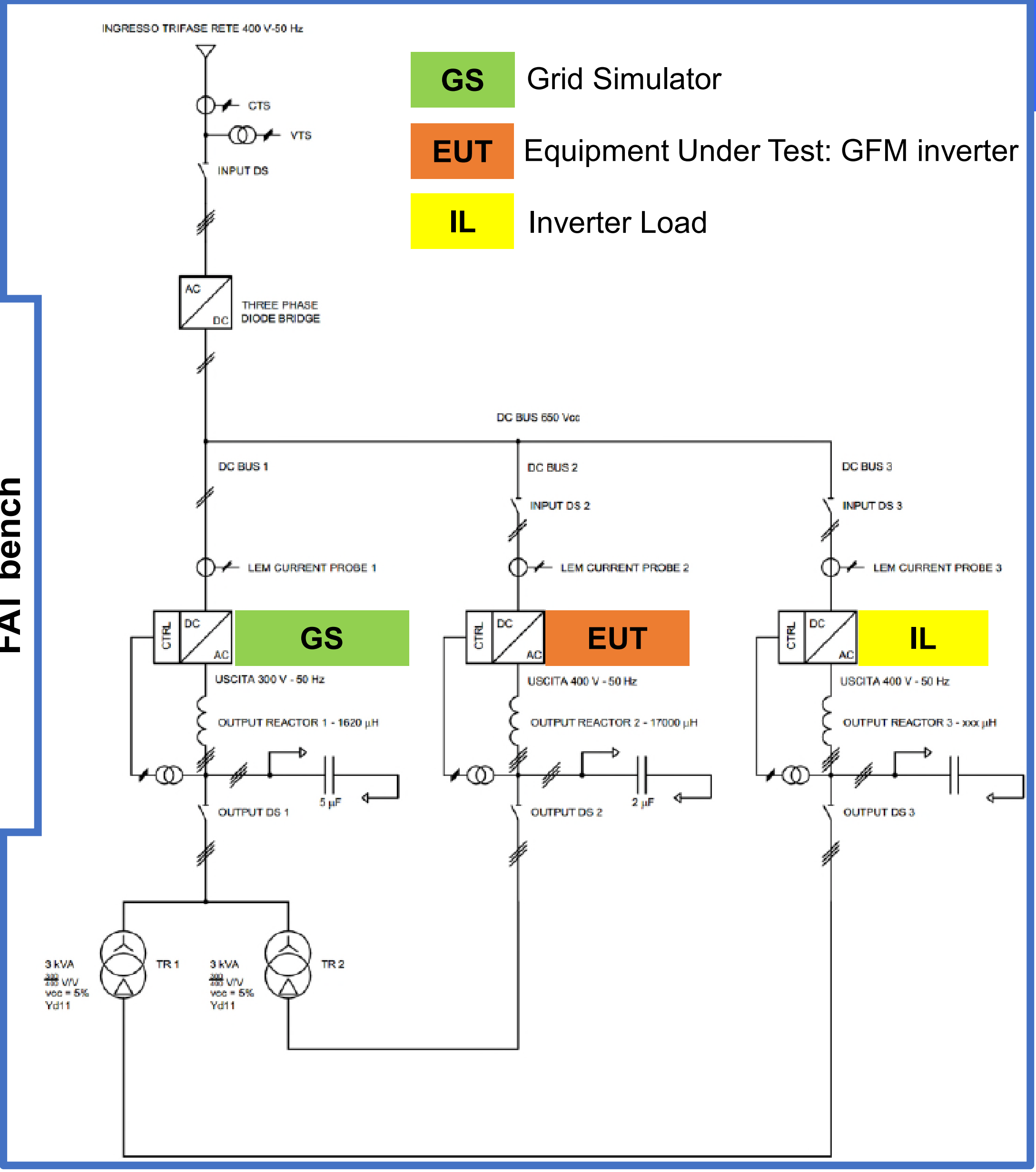
Tests campaign

Factory Acceptance Tests (FAT)

Site Acceptance Test (SAT)

	A. GRID CONNECTED TESTS		
1	Synchronization to the grid	FAT	SAT
2	Control Switch (grid following - grid forming)	FAT	SAT
3	Setpoint tracking (P, Q, V, f)	FAT	SAT
4	Response to P-f disturbance: ▪ Application of ROCOF events, grid side ▪ Application of phase-jump events, grid side	FAT	
5	Response to short-circuits: ▪ Three-phase voltage sags ▪ Bi-phase voltage sags	FAT	
	B. ISLAND TESTS		
1	Black Start	FAT	SAT
2	Setpoint tracking (P, Q)	FAT	SAT

FAT bench



Tests results

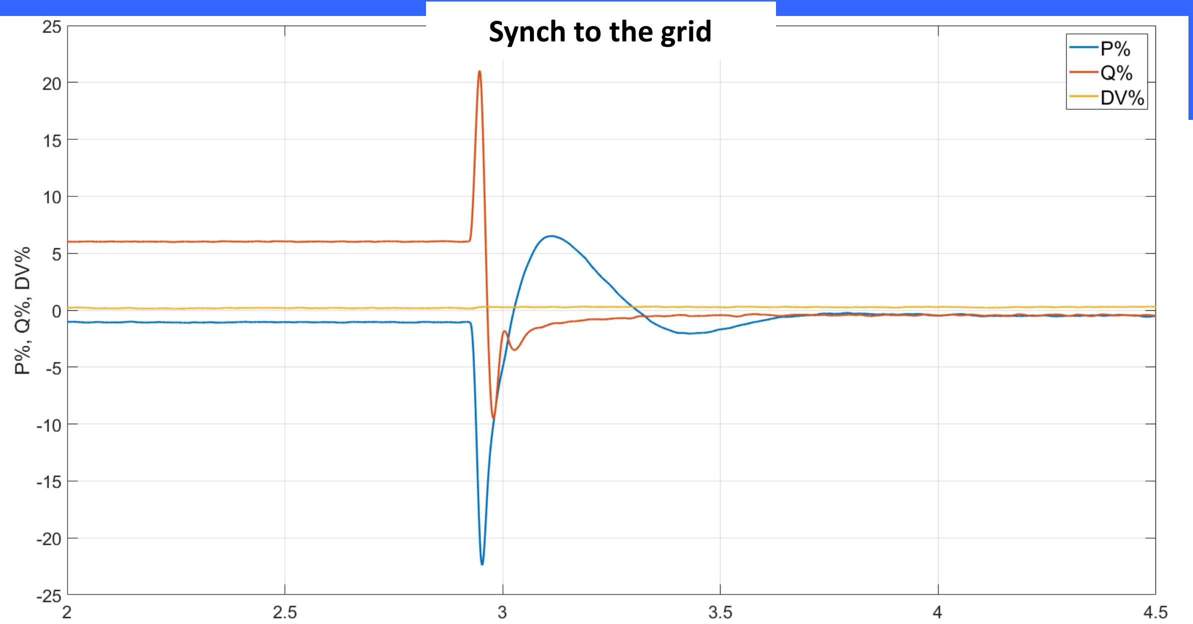
Synchronization to the grid

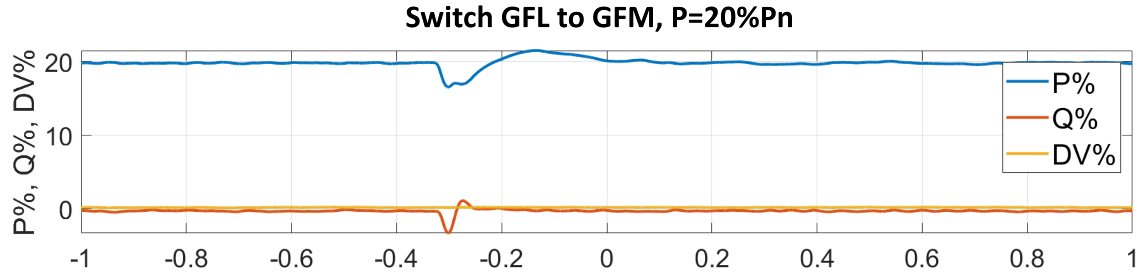
Requirement: The converter must be able to synchronize with the grid without introducing discontinuities or instability during the transition.
Evidence: Always successful.

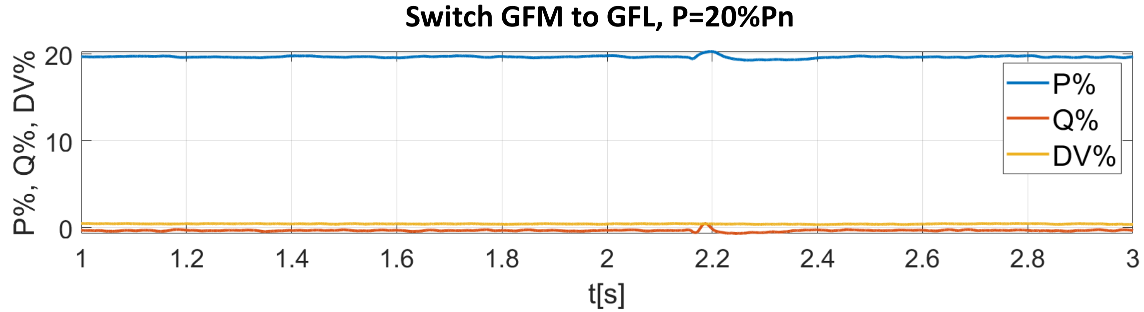
Control switch GFM-GFL

Requirement: The converter must be able to switch in a continuous and stable manner, without excessive waveform spikes (bumpless transition), even when the active power exchanged with the grid is non-zero.
Evidence: The switch occurred bumplessly, even with P = 20% Pn.

KPI	Requirement	Evidence
Settling time	t < 2 s	t ≈ 1,5 s
Overshoot	< 5%	< 5%







Tests results

P Setpoint

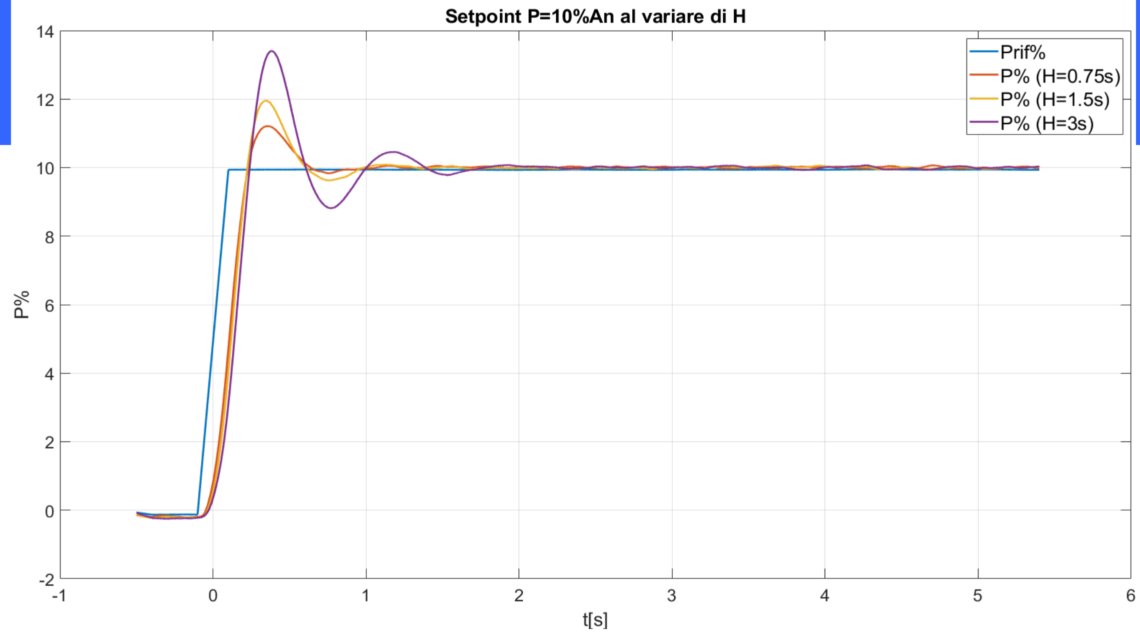
Requirement: The converter must be able to track setpoints accurately and stably, while respecting the maximum allowed overshoot and settling times.
Evidence: The converter tracked the imposed setpoints with stable and acceptable response.

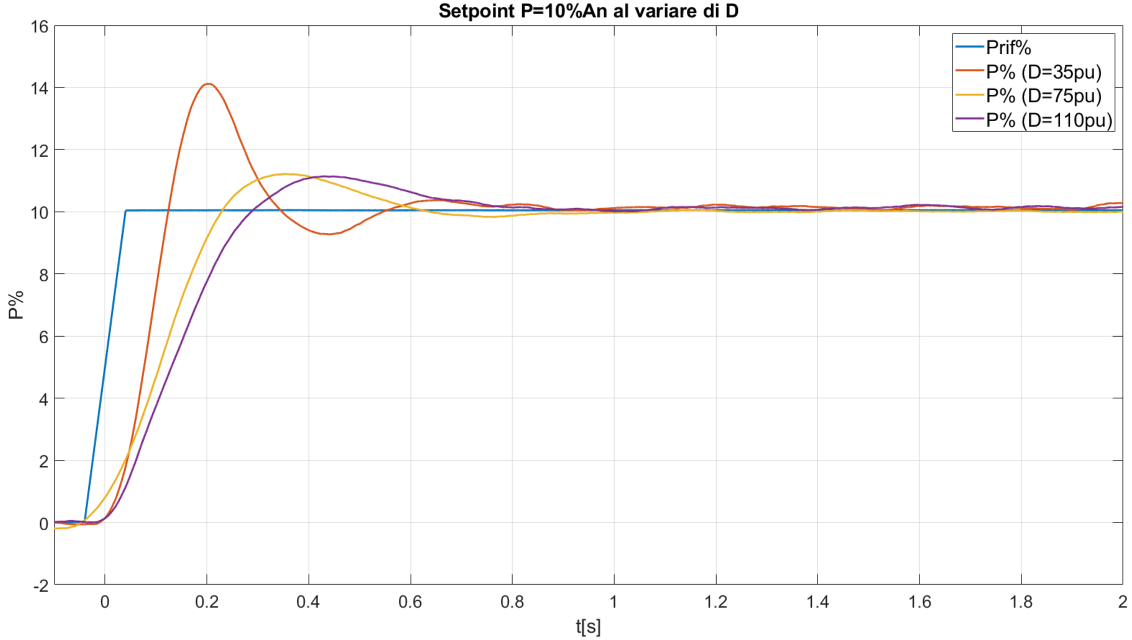
KPI	Requirement	Evidence
Settling time	t < 1 s	t < 150 ms
Overshoot	< 5%	< 5%

Main highlights

As the virtual inertia parameter (H) increases:
- Overshoot increases
- Settling time increases
- Oscillations are less damped

As the damping parameter (D) increases:
- Overshoot decreases
- Settling time decreases
- Oscillations are more damped





Tests results

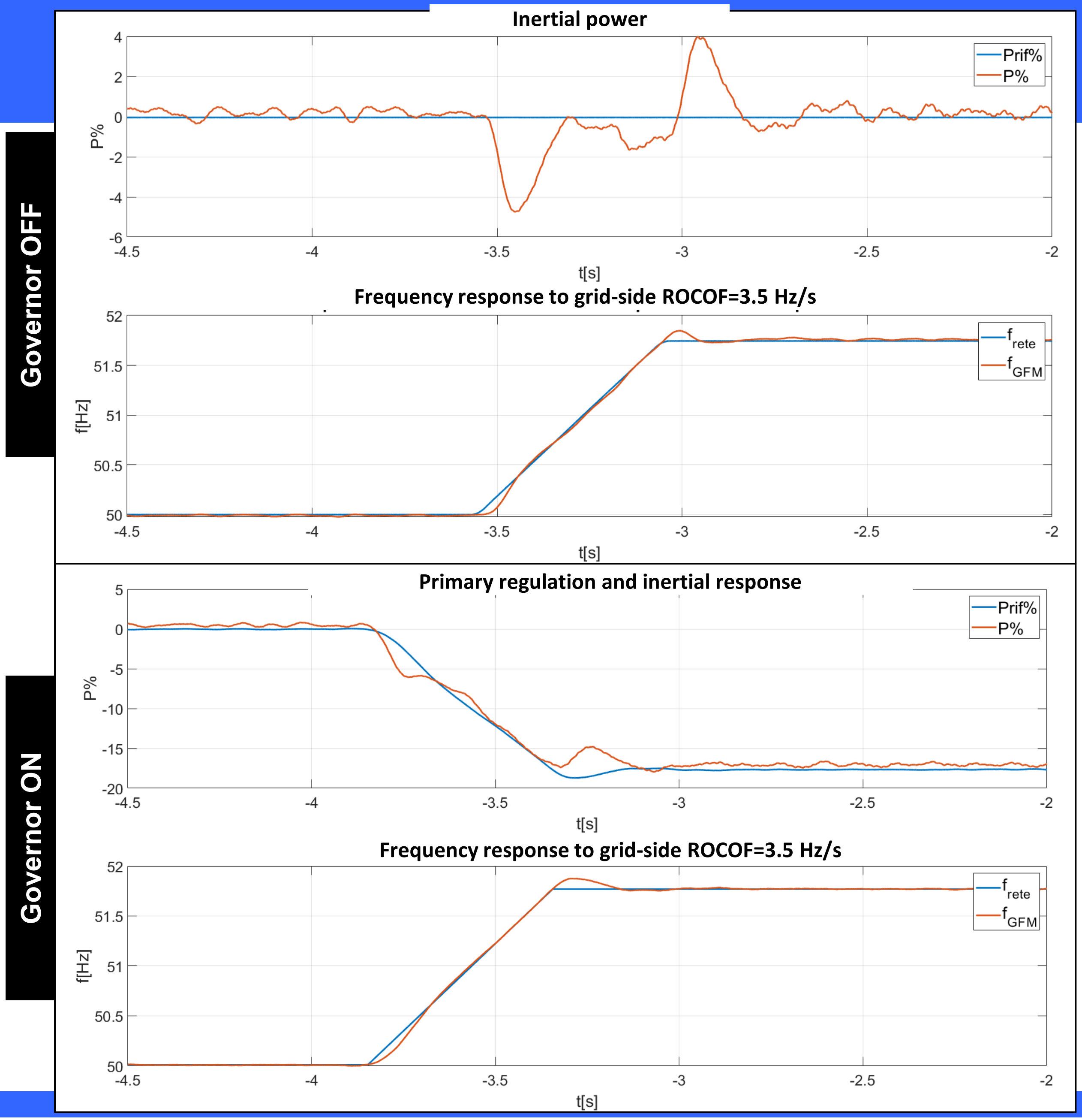
Response to ROCOF event

Requirement: Stability and continuous service must be ensured in the presence of grid-side ROCOF up to 2.5 Hz/s. Active power and frequency should respond with inertial behavior.
Evidence: Test passed with ROCOF of 3.5 Hz/s.

KPI	Requirement	Evidence
Activation time	t < 10 ms	t ≈ 5 ms

Main highlights:

- Active power is delivered in the direction opposite to the frequency variation.
- The internal frequency changes more slowly than the grid frequency, confirming inertial behavior similar to that of a synchronous machine.
- When the governor is activated, there is also an active power contribution from primary frequency regulation.



Tests results

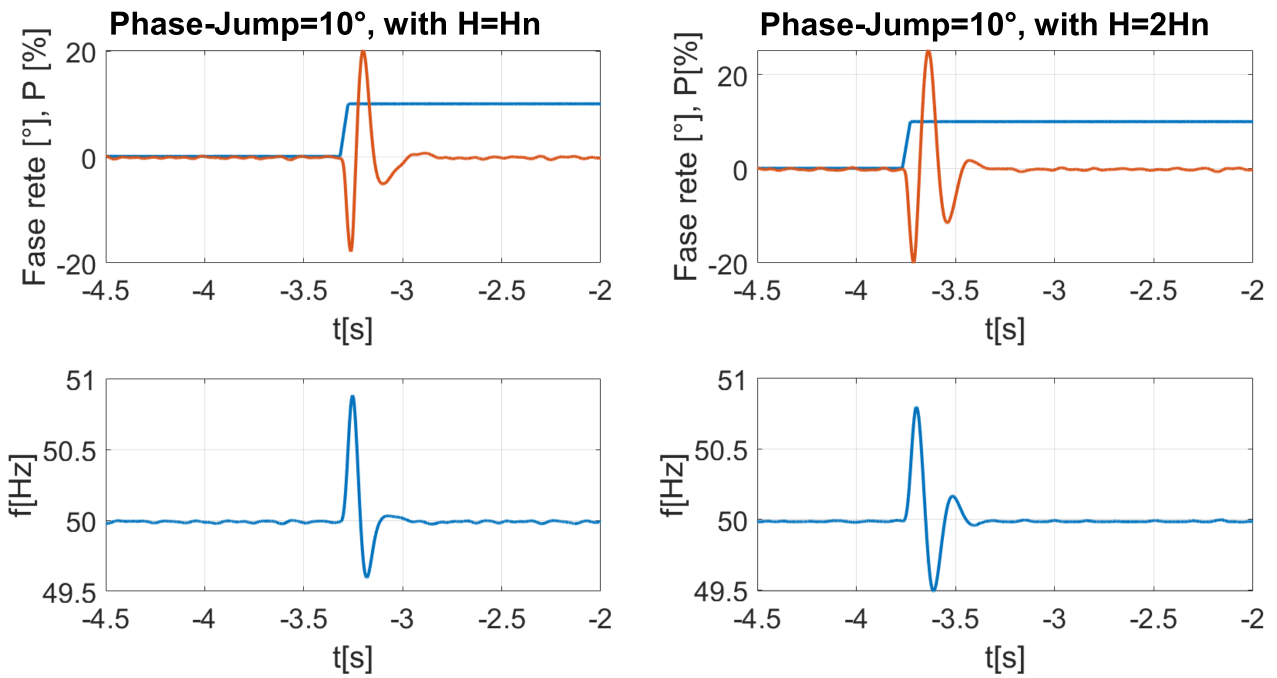
Response to phase-jump event

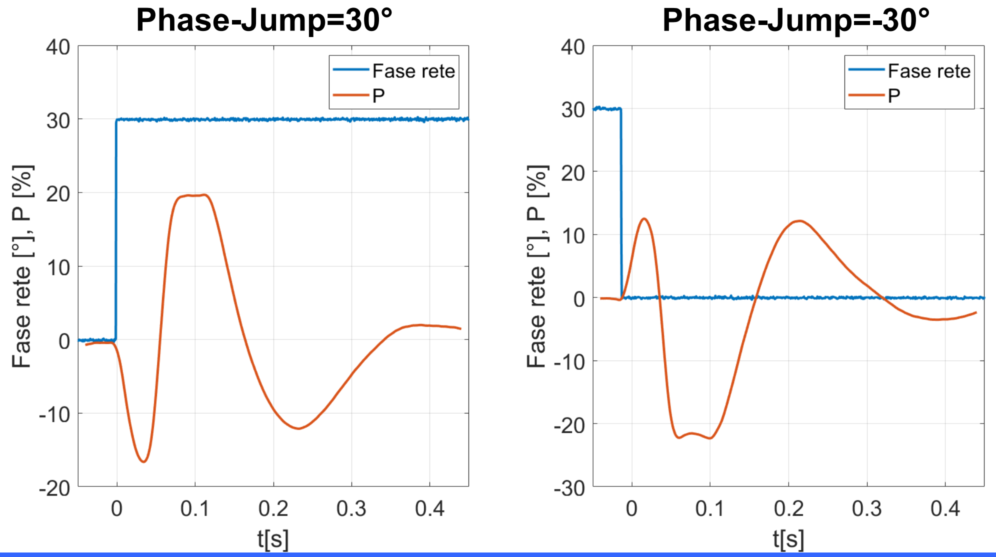
Requirement: Stability and continuous service must be ensured in the presence of a grid-side phase jump up to 30°.
Evidence: Test passed with a phase jump of 30°.

KPI	Requirement	Evidence
Activation time	t < 10 ms	t ≈ 5 ms

Main highlights:

- Spontaneous power response (response time < 5 ms)
- Inverter output power and internal frequency have opposite signs (inertial behavior).
- As H increases, the response is more pronounced but settles more slowly.
- For large phase jumps, the response is limited to prevent current saturation, while still maintaining synchronism with the grid.





Tests results

Short-circuit: response to three-phase grid dips

1. Current injection

Requirement: The converter must deliver current spontaneously during a fault, with amplitude proportional to the voltage dip.
Evidence: Fault current amplitude is proportional to the voltage dip, with the ability to set the voltage dip at which the maximum deliverable current occurs.

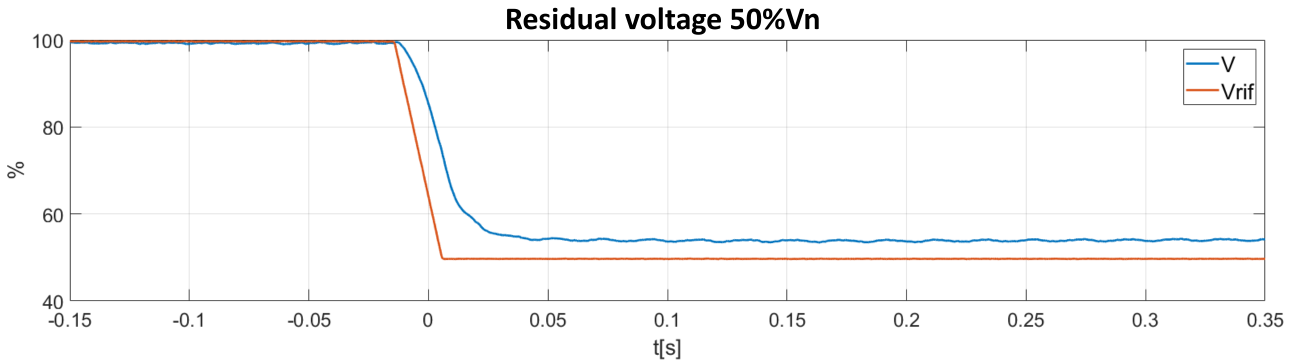
2. Priority: reactive power.

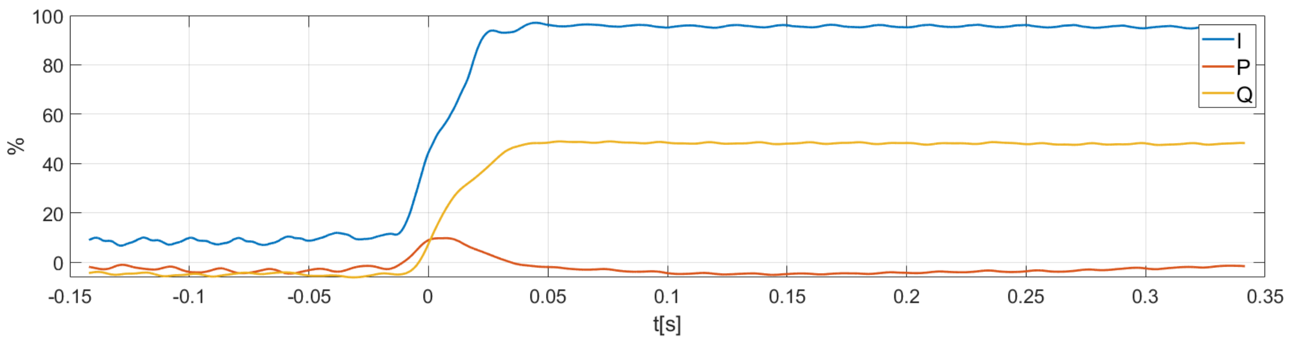
Requirement: The inverter must prioritize reactive current
Evidence: Although the spontaneous response provides for delivering both P and Q, the control tends to prioritize Q and reduce P to zero.

3. *Fault-Ride-Through*

Requirement: As indicated in A79 of Italian Grid Code.
Evidence: no time limits

KPI	Requirements	Evidence
Activation time	t < 10 ms	t ≈ 5 ms
Settling time	t < 300 ms	t < 150 ms





Conclusions

Capabilities

1. A GFM BESS plant can operate connected to the transmission network (RTN), providing grid stability support.
2. The converter autonomously generates voltage and frequency.
3. The converter tracks active and reactive power setpoints with responses similar to those of a rotating synchronous generator (second-order response dependent on H and D).
4. The converter provides spontaneous responses (within 5 ms) to grid disturbances (ROCOF, phase jumps and voltage dips).
5. The grid support capability has been tested even with ROCOF = 3.5 Hz/s*, phase jump = 30°, and voltage dip = 75%.
6. Even in cases of saturation, the inverter remains connected to the grid.
7. Control parameters are tunable and adaptable to the point of connection.

Limits

1. Even though the control parameters are reconfigurable, accurate tuning is required depending on the plant characteristics and the point of connection to the grid.
2. Power oscillations exchanged with the grid have been observed, both during laboratory tests and on-site. Their amplitude is negligible, as it remains within 1–2% of the plant rating. It is likely that further filtering could have reduced them even more.
3. The inverter is current-limited, and its saturation, if not properly managed, can cause a trip. In very weak grid conditions, e.g., in islanded operation, high saturation was found to more easily lead the inverter to disconnect from the grid.
4. Possible interactions with other GFM or GFL inverters are not yet well understood.

NEXT STEPS

- **Assessment of the impacts of the widespread deployment of GFM BESS plants** connected to the transmission grid.
- Definition of **minimum technical requirements for the connection** of future inverter-based plants.
- Design of possible **future demos** on a larger scale or involving different types of plants.

Giuseppe Lisciandrello
giuseppe.lisciandrelo@terna.it

Luca Orrù
luca.orru@terna.it