COORDINADOR ELÉCTRICO NACIONAL

SERVIMOS A CHILE CON ENERGÍA

Grid-Forming Requirements and Deployment Plans in the Chilean Power System

ESIG 2025 Fall Technical Workshop

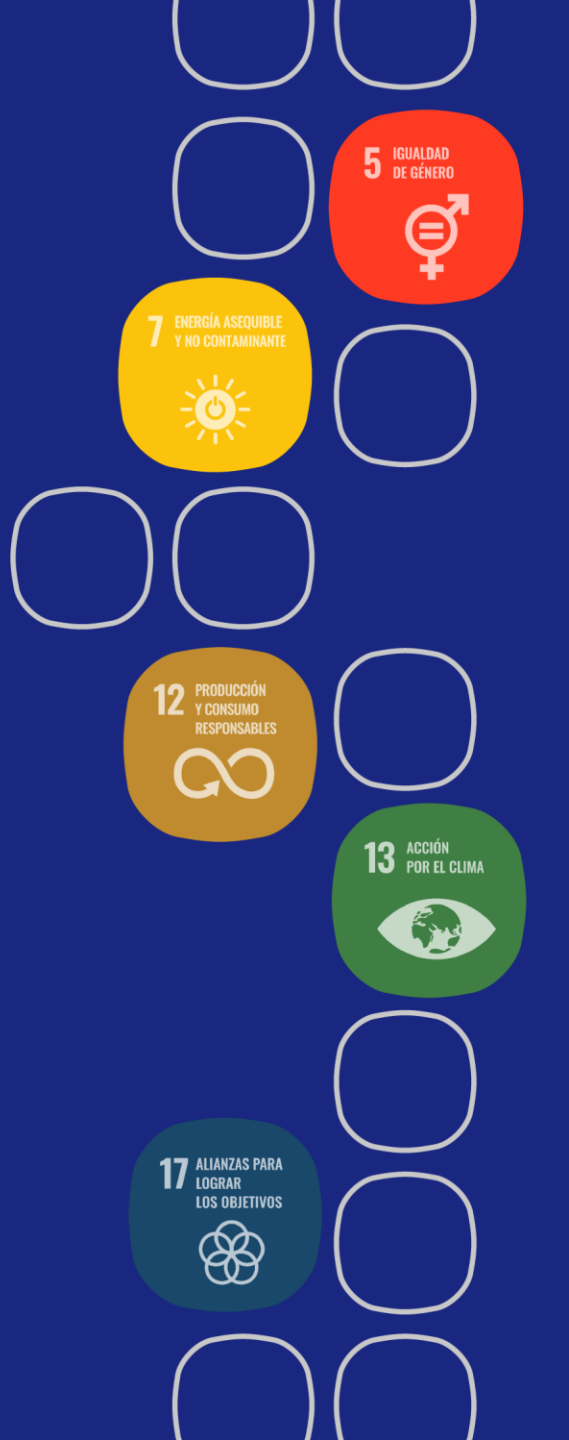
Philadelphia, PA

October 29, 2025

Víctor Velar

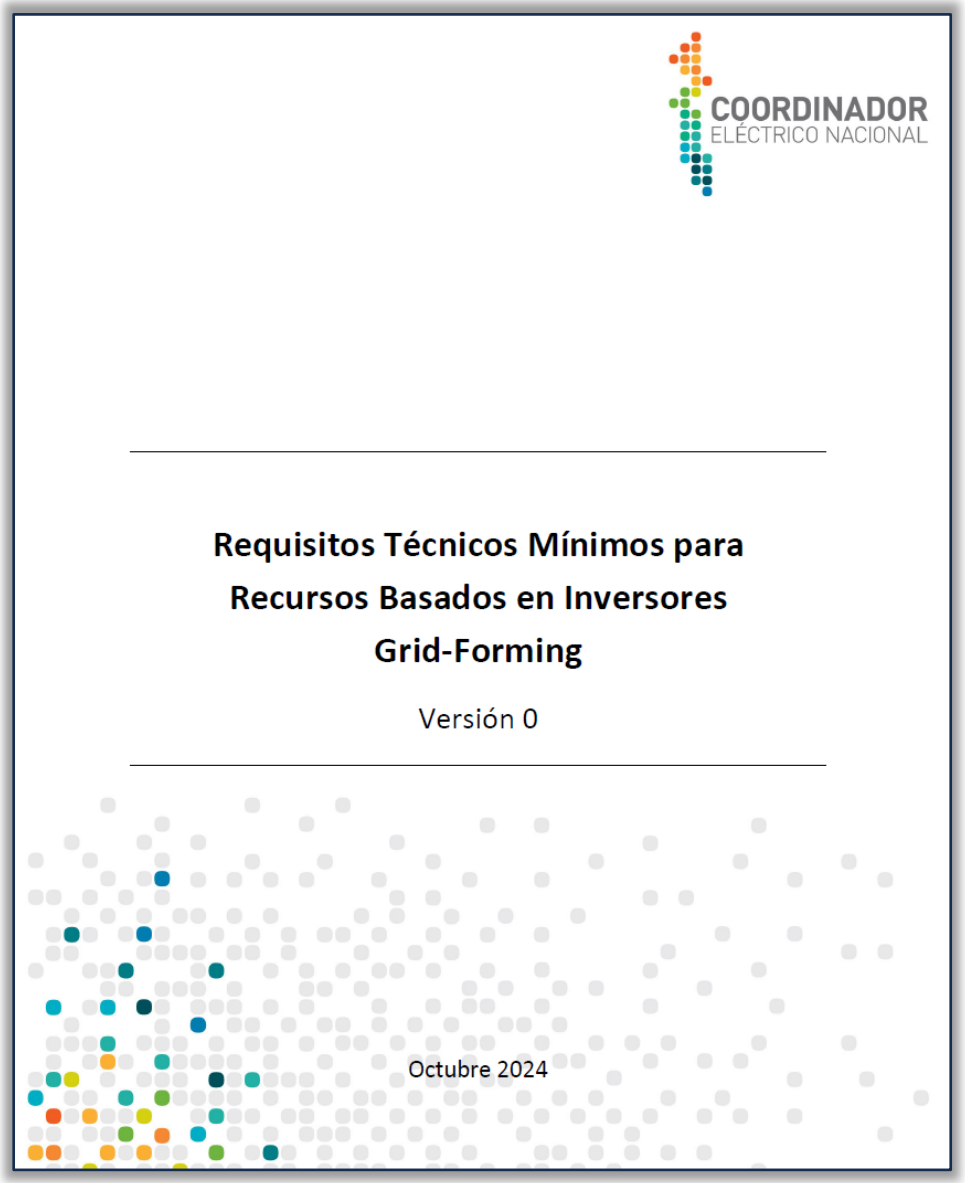
Manager Electrical Studies and Real-Time Simulation

Coordinador Eléctrico Nacional (CEN) - Chile



INTRODUCTION

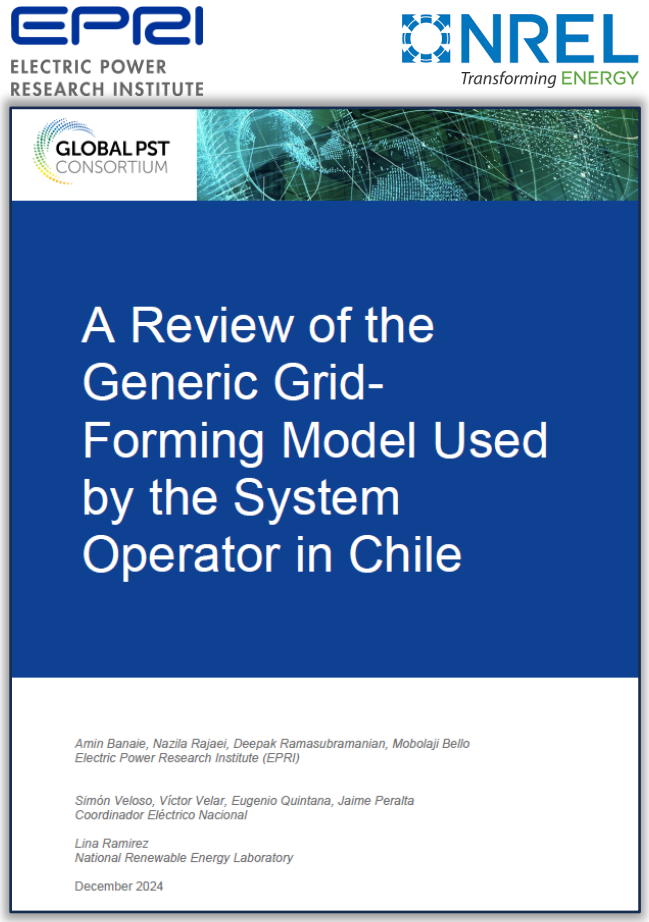
Proposal for minimum performance requirements for GFM IBRs based on international practices and standards, as well as EMT and HIL testing

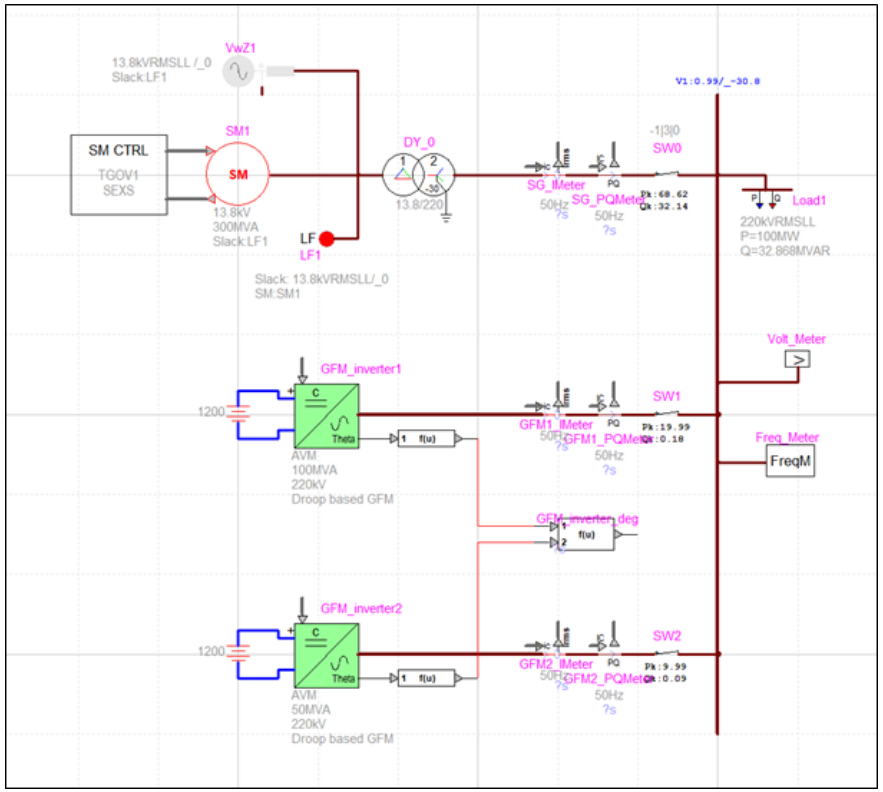


INTRODUCTION

To support the proposal, simulations were conducted in the time domain (EMT).

- ❖ Generic EMT model developed in collaboration with EMTP and EPRI.
- ❖ OEM EMT model provided by a leading vendor.

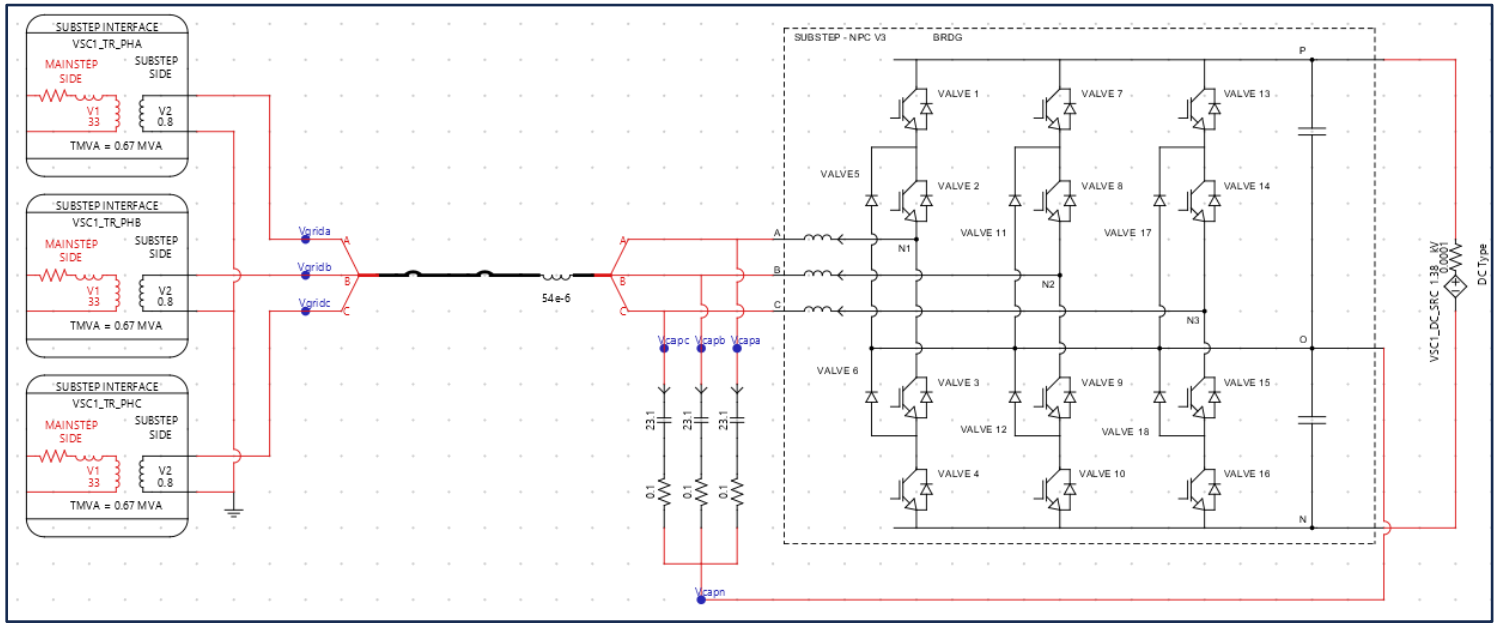




INTRODUCTION

Hardware-in-the-loop (HIL) testing was conducted using a real physical Grid-Forming (GFM) controller from a leading vendor.

In the RTS laboratory of the CEN.



RTS

COORDINADOR
ELÉCTRICO NACIONAL

GFM – MINIMUM REQUIREMENTS

General Structure

Performance Requirements

→Autonomous Operation and Synchronization
→Island Operation
→Oscillation Damping
→Weak Grid Operation
→Power and Reactive Power Contribution
→Frequency and Voltage Response
→Frequency Ride-Through and Response
→Voltage Ride-Through and Response
→Unbalance Compensation (Negative Sequence Current)
→Fault Ride-Through (Symmetrical and Asymmetrical)
→Voltage Phase Jump Response
→Oversizing (Overcurrent Capability)

Additional Capabilities

→Black Start and System Restoration

Modeling and Testing

HIL Simulations

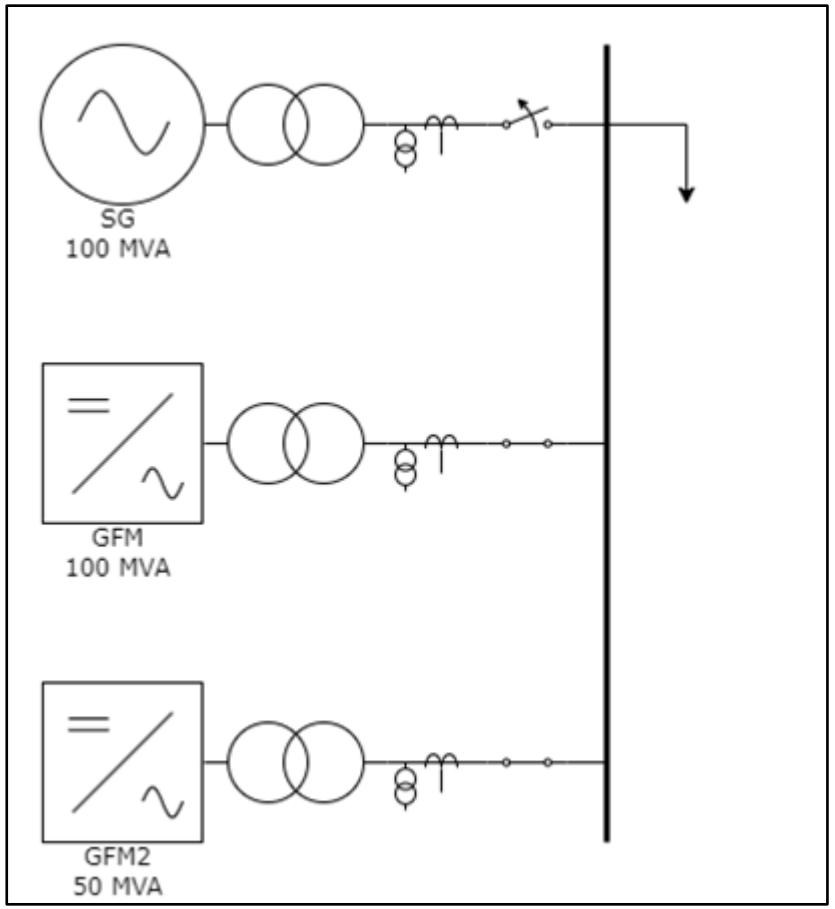
GFM – MINIMUM REQUIREMENTS

Island Operation

GFM IBRs must maintain stable voltage and frequency upon disconnection of the last synchronous machine from the grid.

Stable operation with other GFL or GFM IBRs in the grid.

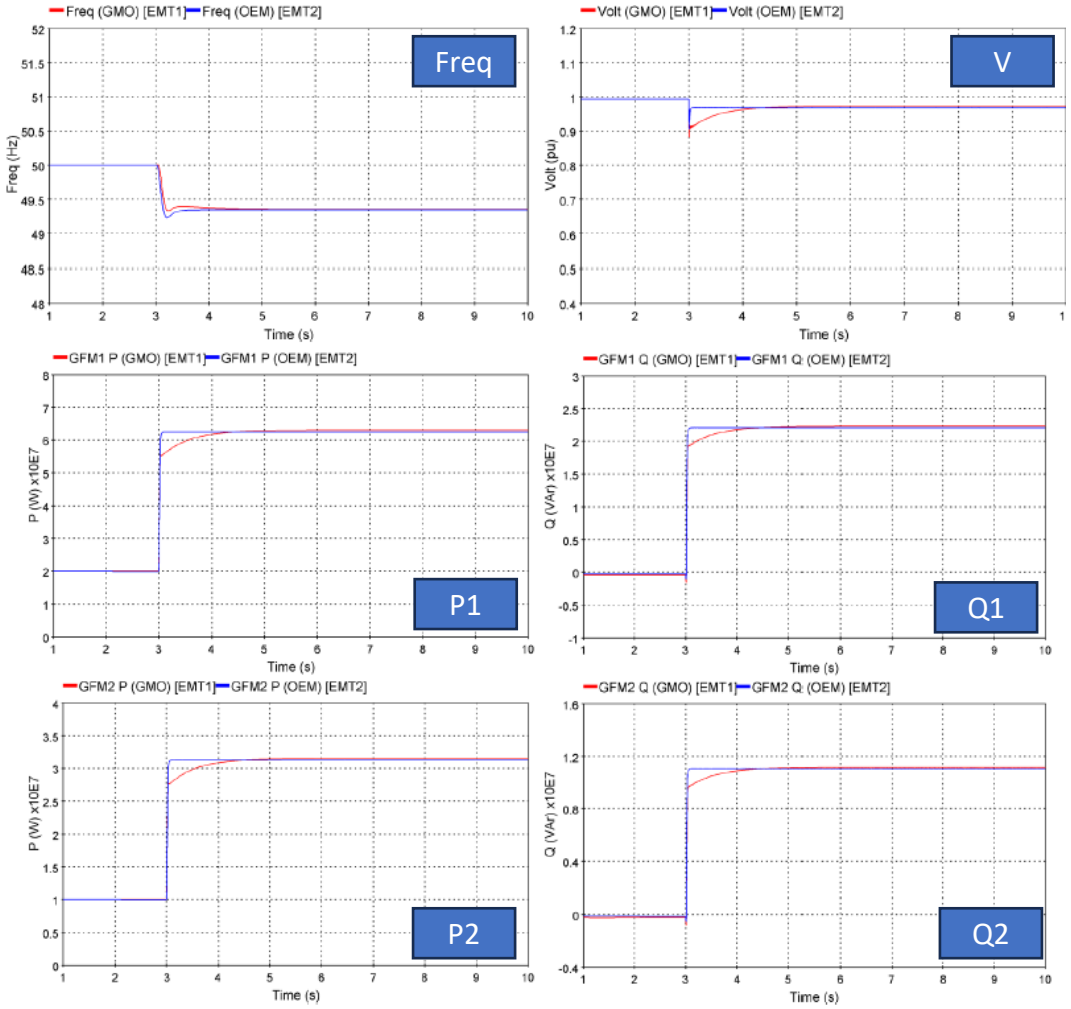
They must transition smoothly and stably between grid-connected and islanded operations (and vice versa).

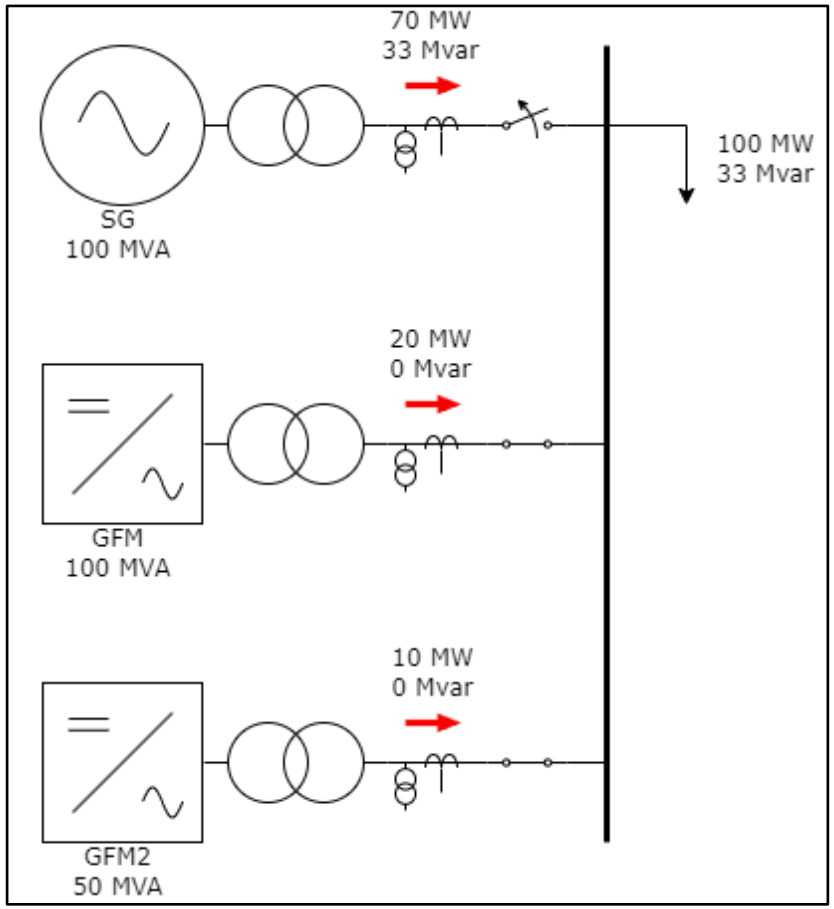


Test Bench 2 for GFM IBRs - AEMO

GFM – MINIMUM REQUIREMENTS

Island Operation (EMT Test)



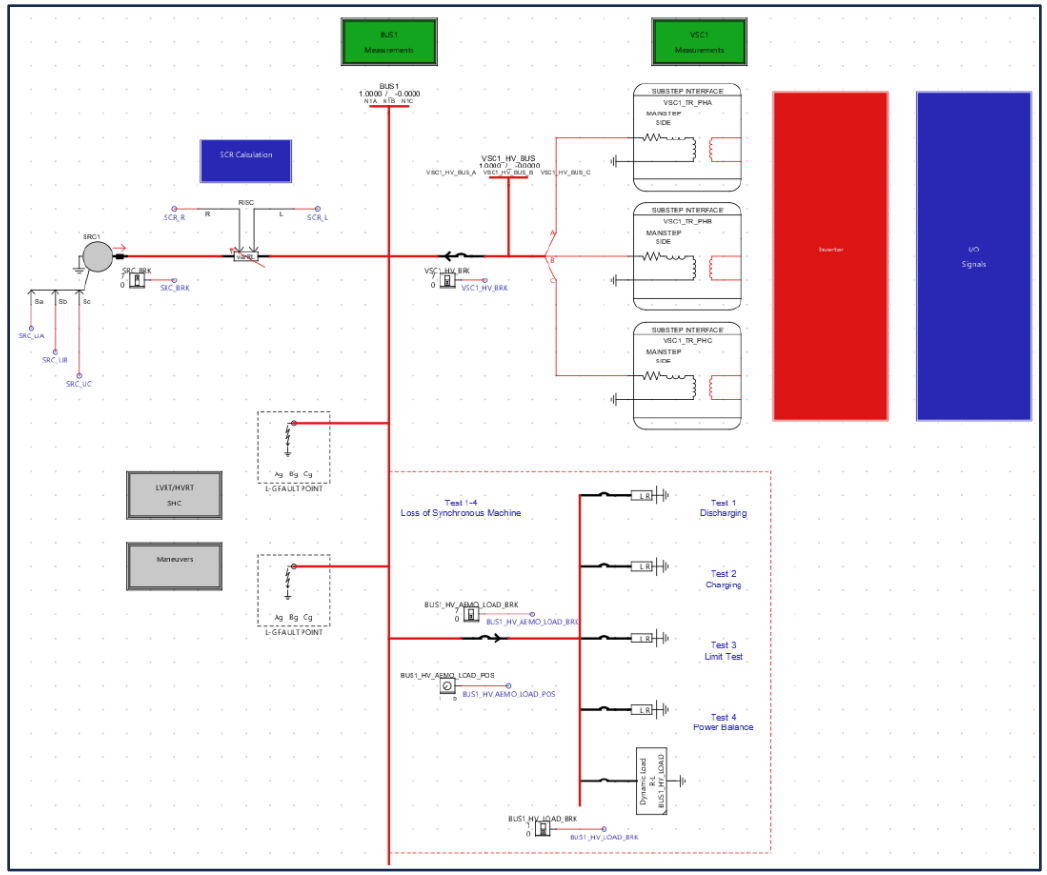


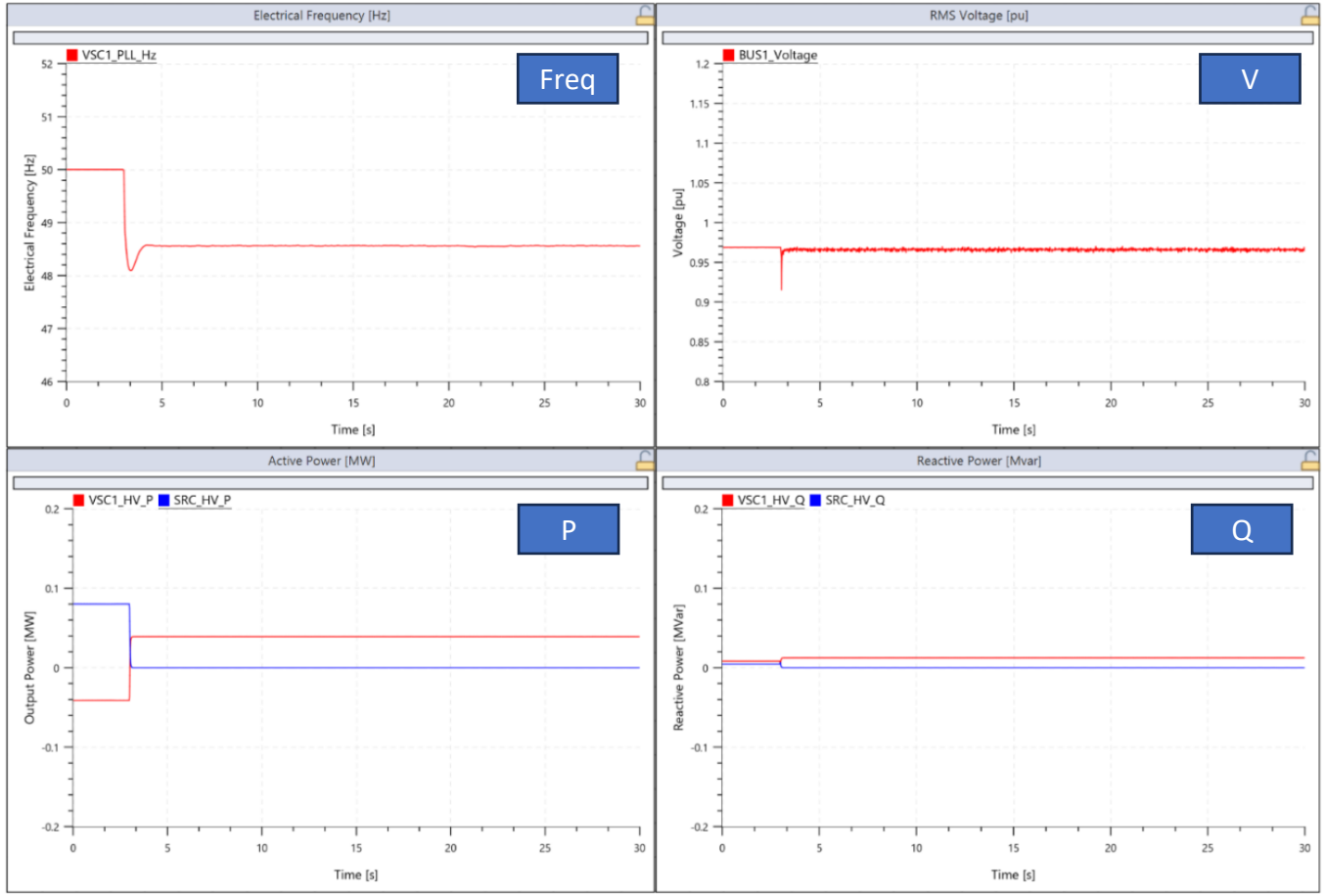
Test Bench 2 for GFM-IBRs AEMO

COORDINADOR ELÉCTRICO NACIONAL

GFM – MINIMUM REQUIREMENTS

Island Operation (HIL Test)

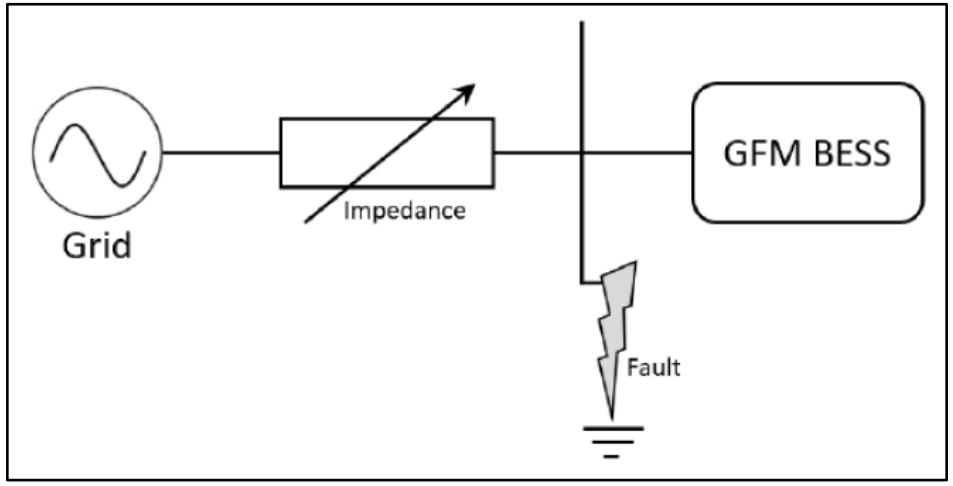




GFM – MINIMUM REQUIREMENTS

Voltage Phase Jump

- GFM IBRs must absorb or inject active and reactive power in response to phase angle changes.
- The maximum angle depends on the grid and must be defined by the system operator.

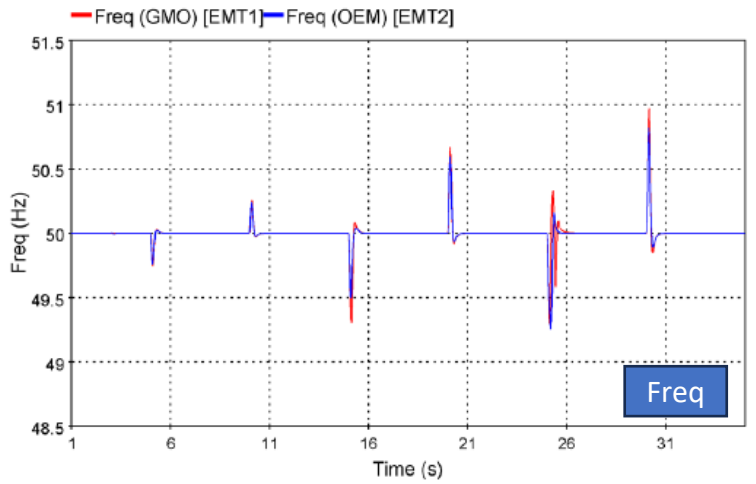


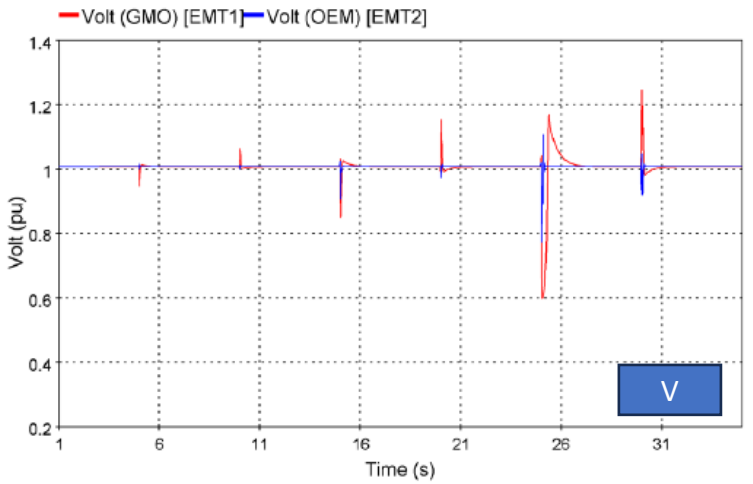
Test Bench 1 for GFM IBRs - AEMO

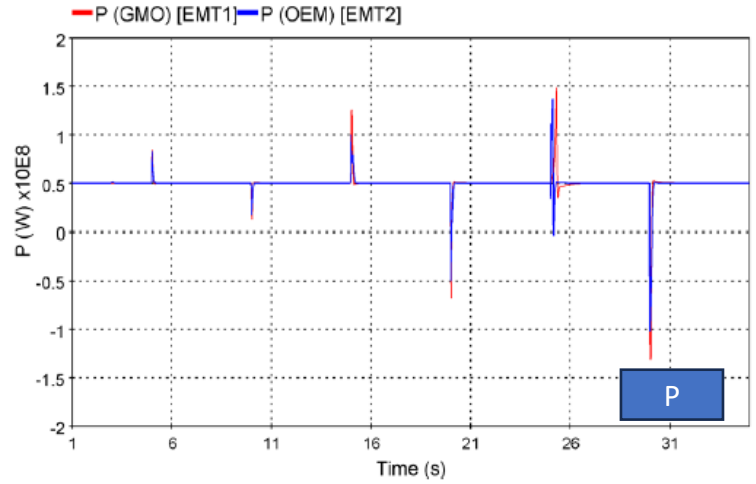
GFM – MINIMUM REQUIREMENTS

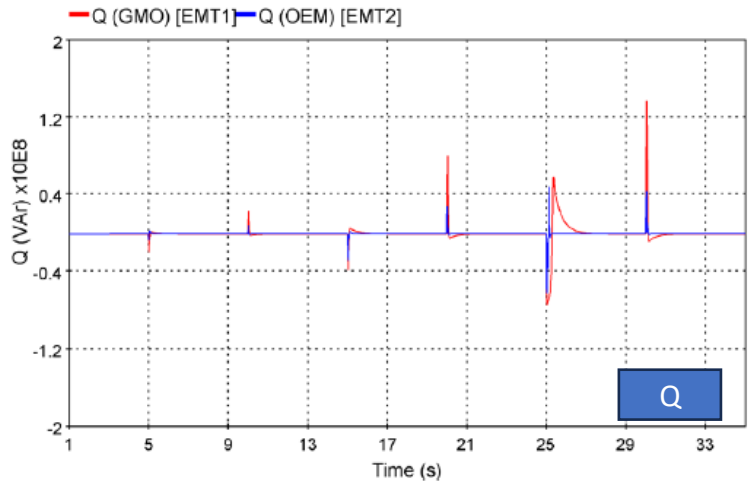
Voltage Phase Jumps (EMT Test)

1. Angle decreased by 10 degrees
2. Angle increased by 10 degrees
3. Angle decreased by 30 degrees
4. Angle increased by 30 degrees
5. Angle decreased by 60 degrees
6. Angle increased by 60 degrees





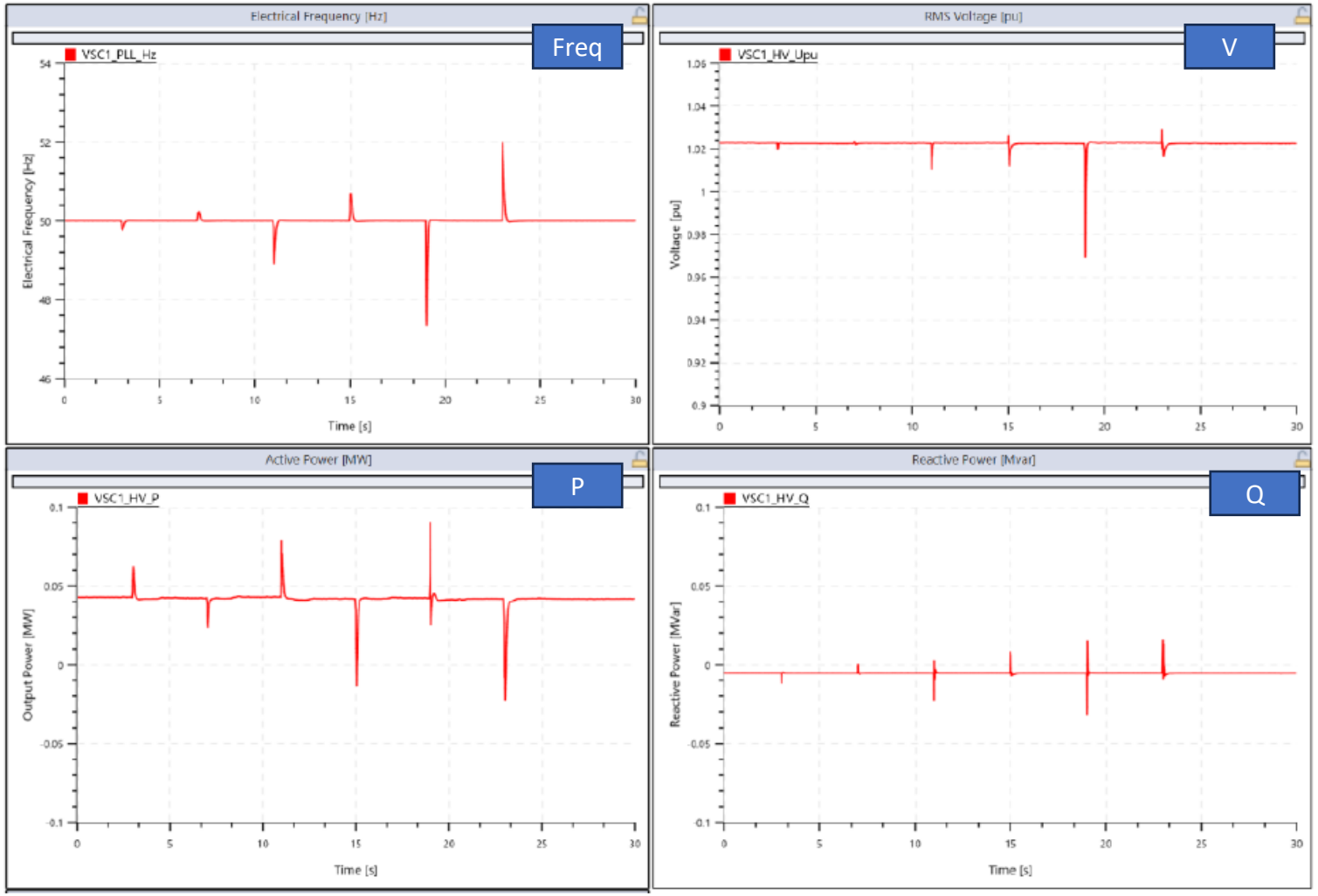




GFM – MINIMUM REQUIREMENTS

Voltage Phase Jumps (HIL Test)

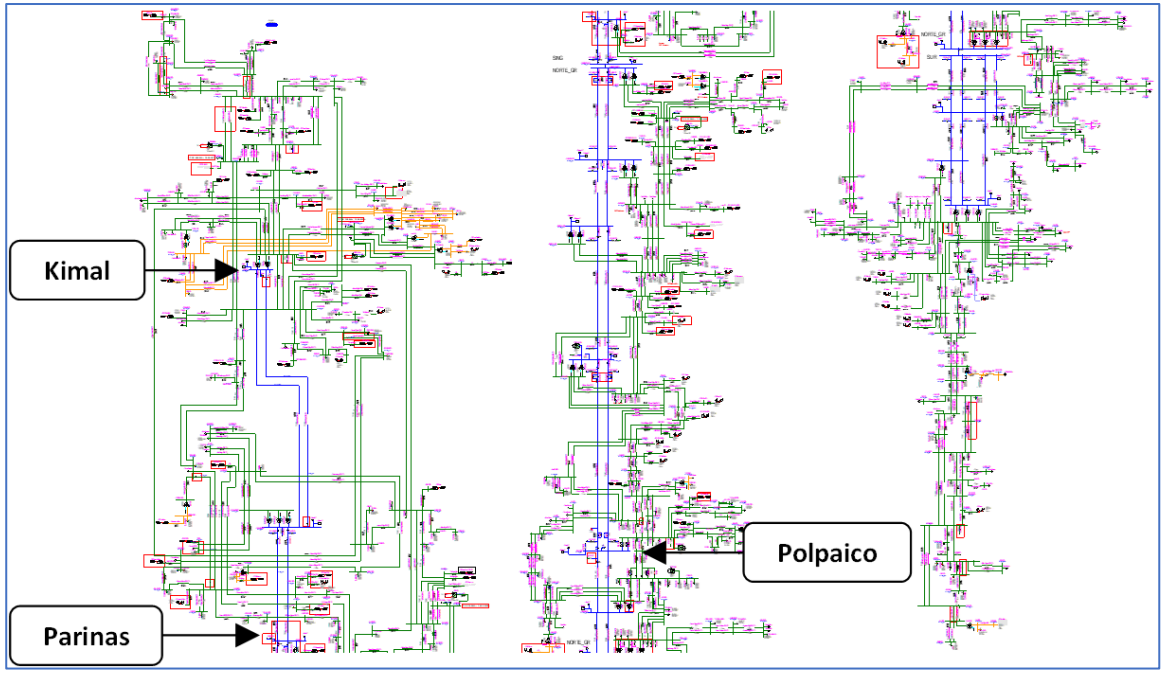
1. Angle decreased by 10 degrees
2. Angle increased by 10 degrees
3. Angle decreased by 30 degrees
4. Angle increased by 30 degrees
5. Angle decreased by 60 degrees
6. Angle increased by 60 degrees



GFM – DEPLOYMENT PLANS

CEN Studies for the integration of GFM

- CEN study on the large-scale integration of GFM in a scenario with 70% wind and solar penetration → *"Dynamic Behavior of Grid-forming Inverters in Large-scale Low-strength Power Grids".*
- Main conclusions:
  - A minimum share of GFM was required (12-15%) to keep the grid stable under extreme events
- Studies for a 90% IBR scenario by 2030 are under development.
- **<u>Preliminary results: BESS-GFM units exhibit comparable (if not superior) performance to synchronous condensers on an MVA-for-MVA basis → Implications for tendering of system strength and inertia services.</u>**



J. Peralta, V. Velar, E. Quintana, J. Mahseredjian, H. Gras, H. Ashourian, **"Dynamic Behavior of Grid-forming Inverters in Large-scale Low-strength Power Grids"**, *IEEE T&D Conference and Exposition, Anaheim, CA*, May 2024.

GFM – DEPLOYMENT PLANS

Industry and Regulatory Response to CEN GFM Requirements

- CEN initiative to publish a proposal for minimum GFM requirements has been well received. Both the regulator and the industry have responded positively.

- BESS projects in Chile are already adopting GFM technology, ensuring smoother integration and system support.

- Chilean updated Grid-Code (2026) **will demand GFM capability for all BESS connected.** Not clear whether activation of GFM will be mandatory for all BESS or only for those **participating in services to provide system strength and inertia.**

GFM – DEPLOYMENT PLANS

Field Pilots and Early Projects

- The CEN is actively promoting field pilots to validate the real-world performance of GFM facilities.
- Currently in contact with several BESS GFM projects.
- Already in the final stages of approval for two pilots.
- BESS GFM options with Black Start capability are currently under evaluation as part of the system restoration plans.
- These collaborations aim to test GFM capabilities under real operating conditions.

GFM – DEPLOYMENT PLANS

On-Site Test Procedure for Connection Approval

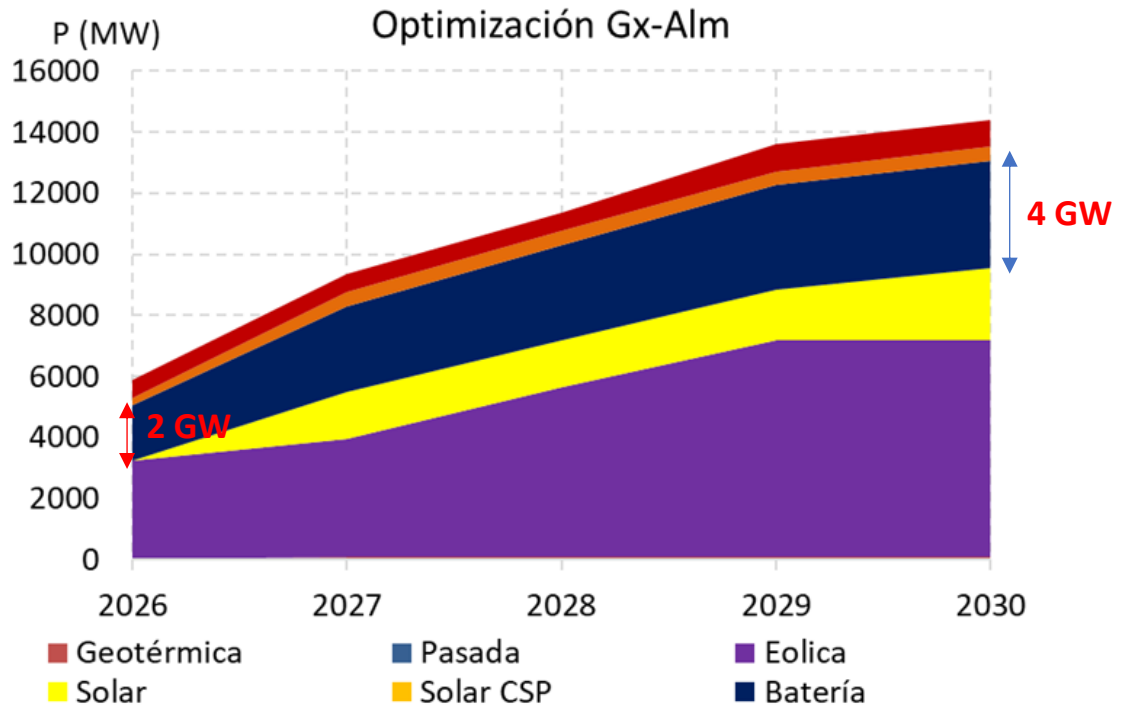
- **Real-condition testing is key for a new technology expected to be widely deployed in a highly IBR-based system.**
- Should on-site validation use a **Grid Simulator Equipment** to reproduce weak-grid and/or low-inertia conditions?
- Or rely on naturally occurring operational events in the grid?
- Are **HIL/CHIL lab/factory tests** sufficient for “hard tests” (FRT, Phase-Jump)?

Source: Shahil Shah, National Renewable Energy Laboratory.

GFM – DEPLOYMENT PLANS

Imminent Roll-Out

- The deployment of GFM technology is imminent due to the sharp increase in BESS projects expected to connect in the short and medium term.
- The recently proposed update to the Chilean Grid Code requires that all new BESS installations be capable of operating in GFM mode.
- This regulatory shift underscores the urgency for developers and OEMs to prepare for GFM implementation.



GFM – REQUIREMENTS & DEPLOYMENT

Conclusions

GFM technology is essential for enabling the energy transition process.

It is critical that ALL new BESS equipment possess basic GFM capabilities (core capabilities).

Incorporating these minimum requirements into the Chilean Grid Code is underway.

Validated EMT OEM models with lab and field testing are fundamental.

On-site test procedures for connection approval must balance accuracy with cost/feasibility.

Chile: Imminent GFM deployment is driven by BESS growth and upcoming Grid Code requirements

COORDINADOR ELÉCTRICO NACIONAL

SERVIMOS A CHILE CON ENERGÍA

Thank You