# Large-Scale EMT Modeling and Analysis: Applications in the Chilean Power Grid

Dr. Jaime Peralta

Coordinador Electrico Nacional (CEN)

July 2024

# Coordinador Electrico Nacional – CEN

Independent technical organization responsible for the reliable, secure and economic operation of the Chilean national power grid

**MAIN FUNCTIONS:**

- Guarantee a secure and economic operation of the power grid
- Ensure open access to transmission system
- Administer wholesale energy and AS markets
- Propose a plan for expansions of the transmission system
- Conduct international tenders for new transmission projects
- Manage interconnection process of new G-T-C assets
- Monitor market competition conditions
- Promote innovation, research and development

COORDINADOR ELÉCTRICO NACIONAL

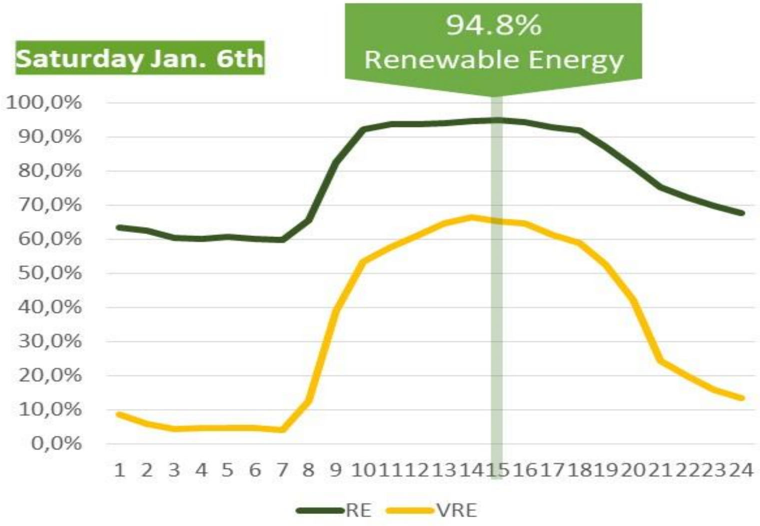
# Electricity Market in Chile

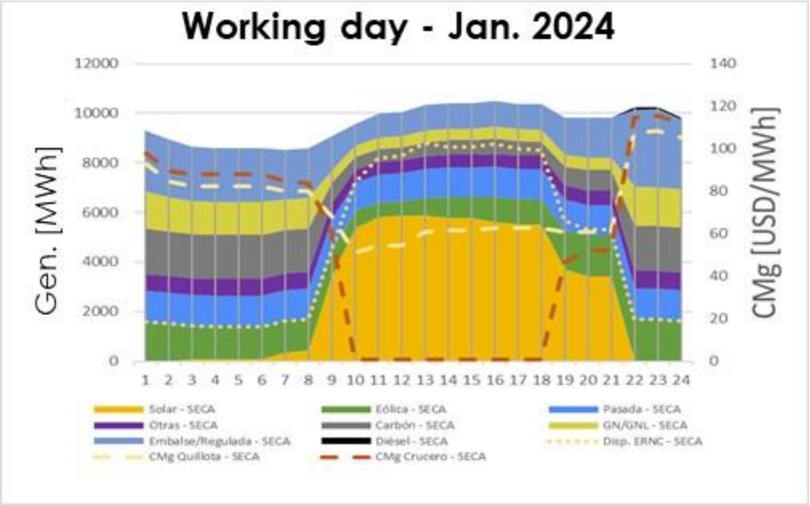
## Facts 2023:

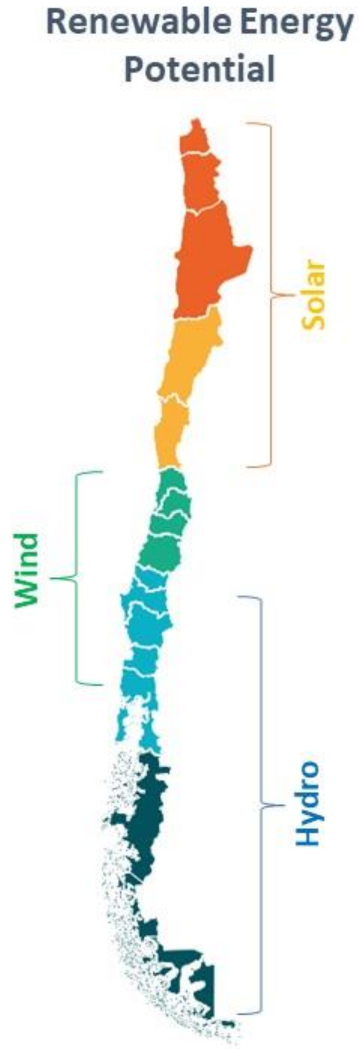
- ✓ Energy: 83,637 GWh
- ✓ Capacity: 34,321 MW
- ✓ Peak load: 11,549 MW
- ✓ VRE (Wind/Solar): 31.1%
- ✓ VRE Peak: 71.2%
- ✓ Transmission: 37,353 km

## Long-term RE Goals:

- ✓ Carbon Neutrality by 2050
- ✓ Decarbonization before 2040
- ✓ 100% RE by 2030 (85% VRE)



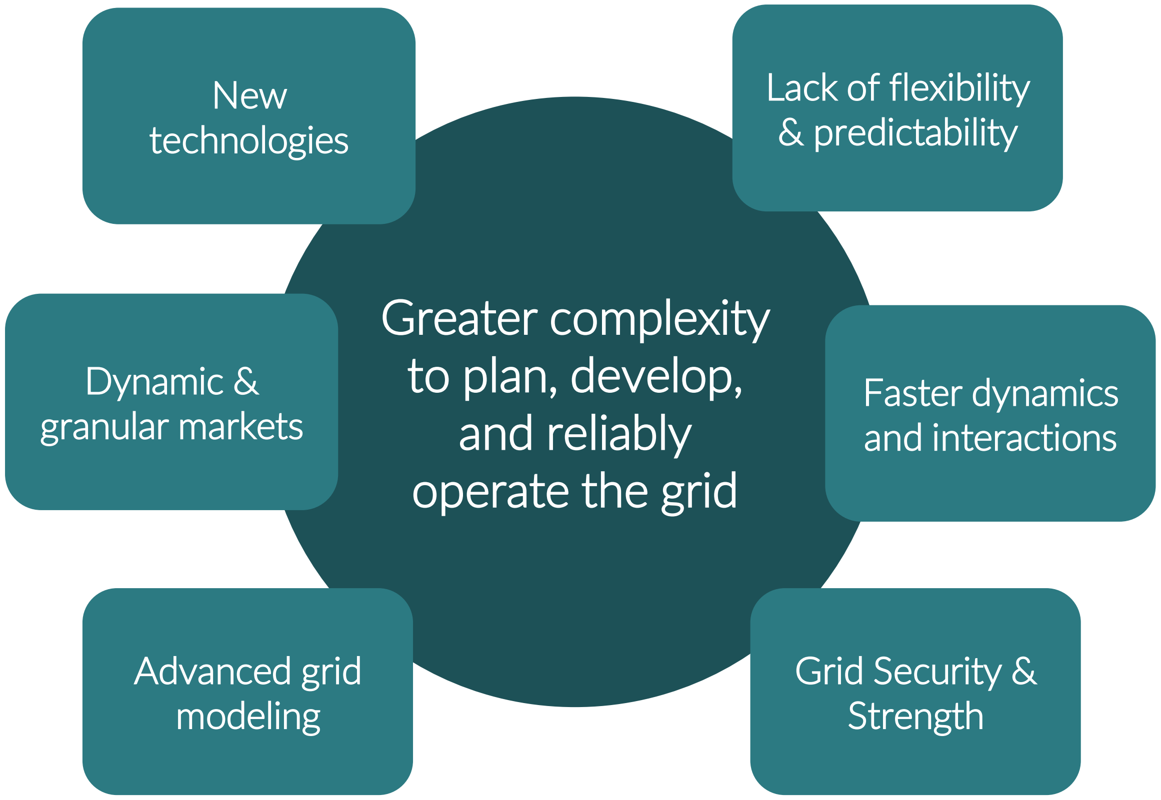



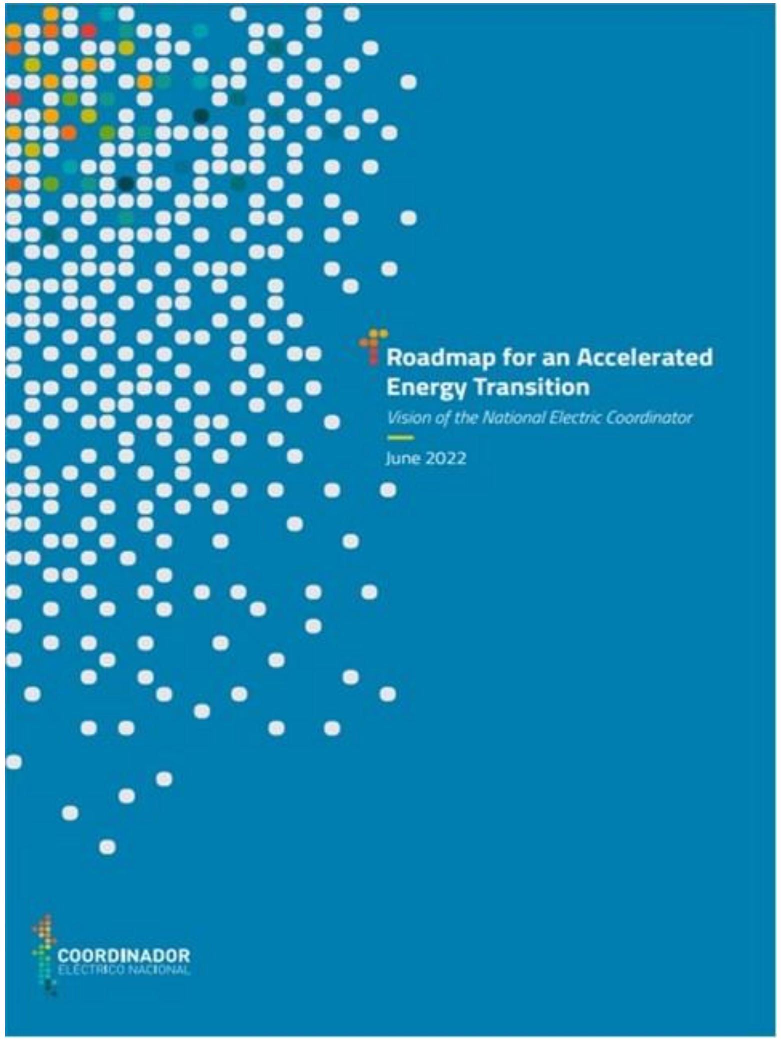
# Context

- ✓ New challenges introduced by massive integration of IBR-based VRE
- ✓ Reduction of system strength due to decarbonization process
- ✓ Faster system dynamics and control interactions
- ✓ Brownouts due to unexpected VRE tripping
- ✓ Little grid support (capabilities) from existing GFL IBRs
- ✓ Lack of standards for new enabling technologies (GFM)
- ✓ Grid modelling and numerical issues in classic tools

**CHALLENGES OF THE GRID OF THE FUTURE**



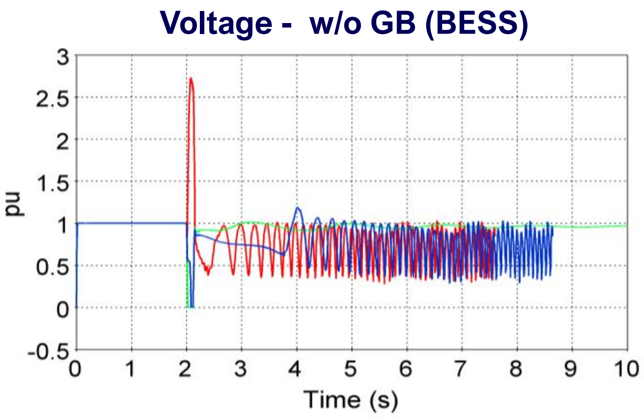
# Roadmap for the Energy Transition

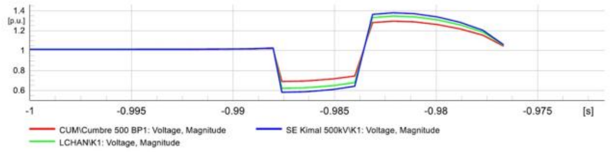


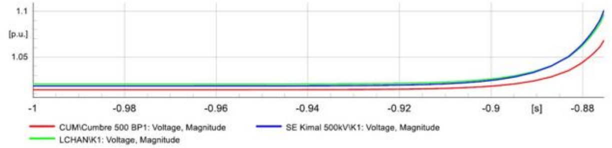

- ✓ Grid virtualization, planning & operational tools
- ✓ Integration of 1000MVAr of synchronous condensers
- ✓ BESS Grid Booster Project (Virtual Transmission)
- ✓ Real-time ESCR monitoring in control room
- ✓ **EMT (EMTP®) model of SEN (Chilean's power grid)**
- ✓ **EMT Connection Tool (on cloud)**
- ✓ **Advanced monitoring for real-time operation (EMT-DSA)**
- ✓ **Wide-Area Grid-forming EMT Study**
- ✓ **Technical requirements and testing of GFM IBRs (G-PST-NREL-EPRI)**
- ✓ Grid-forming testing in RT Lab & on-site pilot project

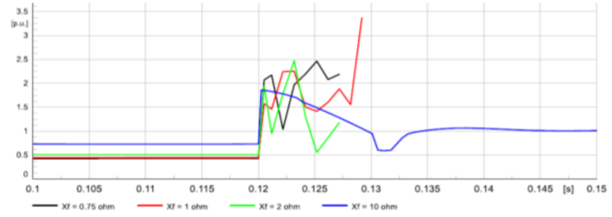
# Challenges with Existing RMS Tools

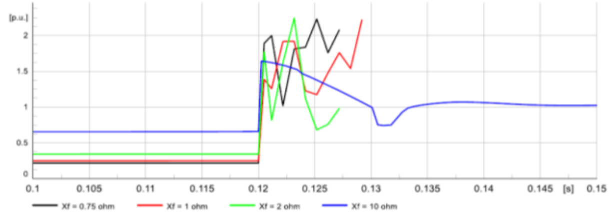
- Modeling of MOVs in 500kV series compensation
  - MOVs not modeled SC not bypassed: Numerical instability problems arise in RMS tool due to the large overvoltage
  - MOVs not modeled, SC bypassed: Optimistic (inaccurate) RMS approach
  - MOVs accurately modeled with non-linear curve: Realistic approach
- Incapable to replicate real events (brownouts) in low-strength grid
- Numerical instability with very high levels of VRE
- RMS oversize/overestimate share of GFM requirements vs. EMT (30% vs. 10%)



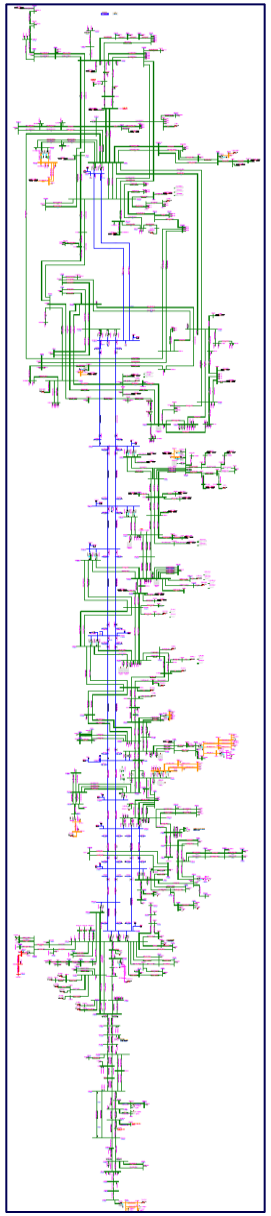


# Advanced EMT Grid Modeling – Approach

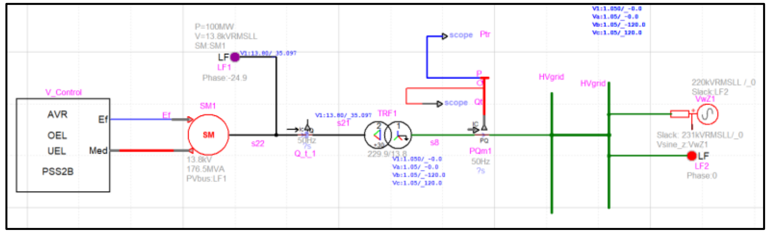
- Collaboration agreement with PGSTech (EMTP®)

- First EMTP® model of Bulk Transmission System
  - ✓ 500 kV and 220 kV systems (3000 km)
  - ✓ +150 generators >20 MW (~100 WPs & PV + ~50 SM)
  - ✓ ~ 15 FACTS (SVC, SVC Plus and STATCOMS)
  - ✓ IBR-based VRE share around 50% (now 70%)
  - ✓ 500 3ph buses, 8000 nodes, 87000 control blocks

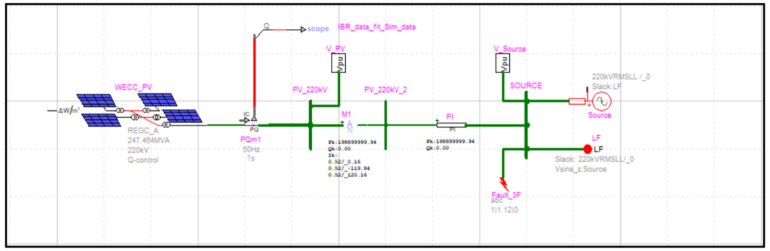
- Model validation & calibration
  - ✓ Flat start initialization from multiphase load flow
  - ✓ Initially with IBR models from the EMTP® renewable library
  - ✓ Validation against RMS tool models (DIgSILENT Power Factory)
  - ✓ Multiple test: step changes (P, Q, V) and faults
  - ✓ *IBR_data_fit* tool was used to calibrate control parameters (PSO - Particle Swarm Optimization Algorithm)



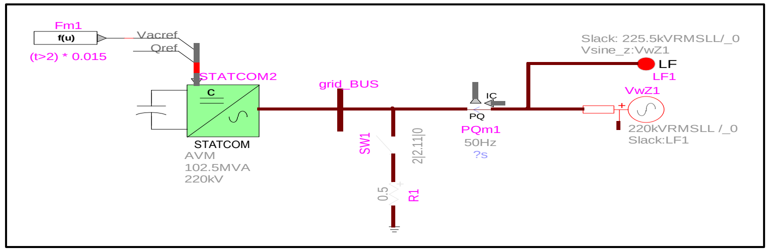
**Synchronous machines**



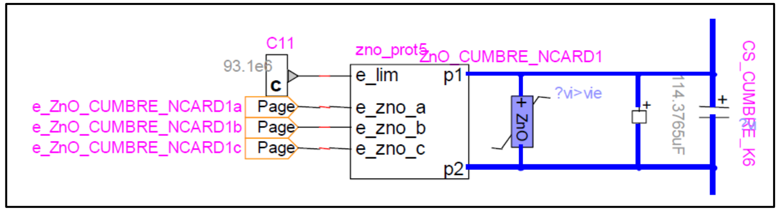

**VRE (IBR) generation**



**Dynamic Var compensation**




**Series Compensation (MOVs)**



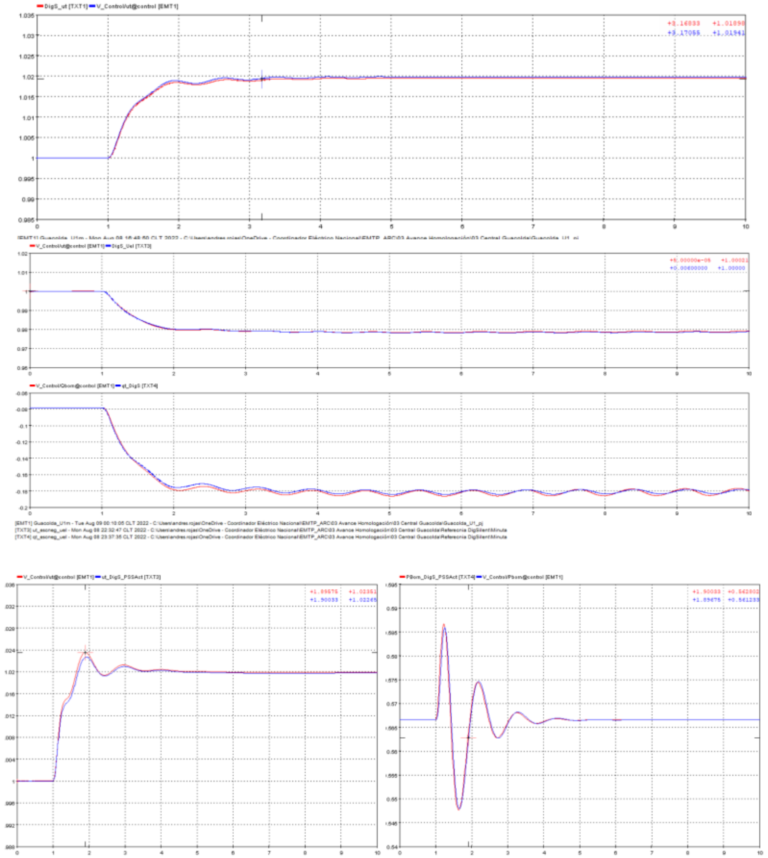



OAK RIDGE National Laboratory

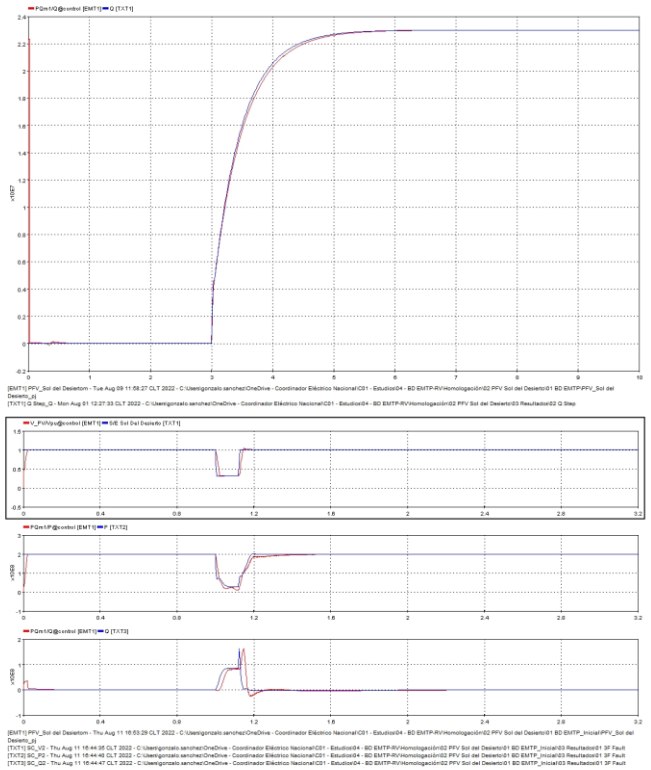
# Advanced EMT Grid Modeling – Model Validation

DIgSILENT blue, EMTP® in red

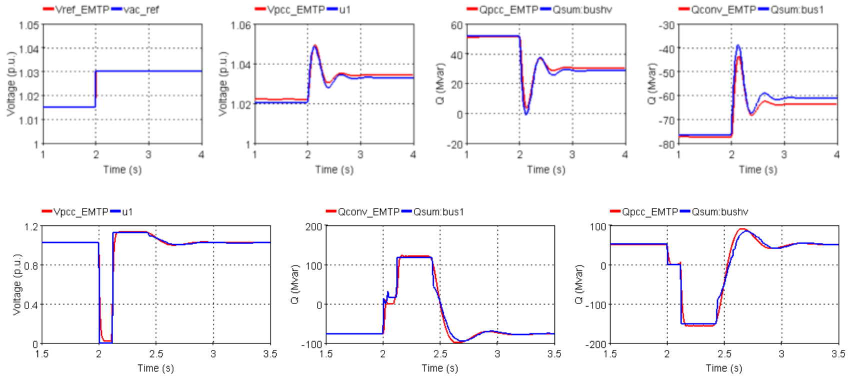
**SM - GUACOLDA**



**FVP - SOL DEL DESIERTO**



**STATCOM – C. NAVIA**



# Advanced EMT Grid Modeling – Computing Performance

## EMT Parallelization Test (New EMTP® release)

**Simulation Computing Performance**

| Δt=50 μs, 5 s simulation | Time (s) | Speed-up |
|---|---|---|
| Reference case (1 CPU) | 620.55 | 1 |
| Parallel solutions (10 CPUs) | 496.13 | 1.25 |
| Parallel solutions (20 CPUs) | 392.73 | 1.58 |
| Parallel solutions (30 CPUs) | 288.22 | 2.15 |
| Parallel solutions (40 CPUs) | 195.87 | 3.16 |
| Parallel solutions (50 CPUs) | 102.14 | 6.07 |
| Parallel solutions (56 CPUs) | 74.4 | 8.34 |
| Parallel solutions (60 CPUs) | 65 | 9.55 |

← Equivalent to RMS performance

# Process & Data Requirements

- Procedure for EMT Model Validation and Homologation
  - ✓ Use of EMTP® software
  - ✓ Focus on VRE, BESS, SGs, HVDC, FACTS
  - ✓ Standard (open) and detailed (OEM) models (black-box)
  - ✓ Validate against RMS models, and field and factory tests
  - ✓ DLL modeling recommended (mandatory in the future)
  - ✓ Models confidential to protect IP rights
- System data
  - ✓ Transmission parameters available from *Infotecnia* (ISO database)
  - ✓ Operation scenario (load and gen. dispatch) imported from Power Factory database
- Models requested in two stages
  - ✓ 1st Stage: Standard library model (i.e., WECC for solar and wind)
  - ✓ 2nd Stage: Detailed (DLL) model from manufacturers (OEM)
  - ✓ Around 40% of models have been delivered


COORDINADOR ELÉCTRICO NACIONAL

Procedimiento Interno

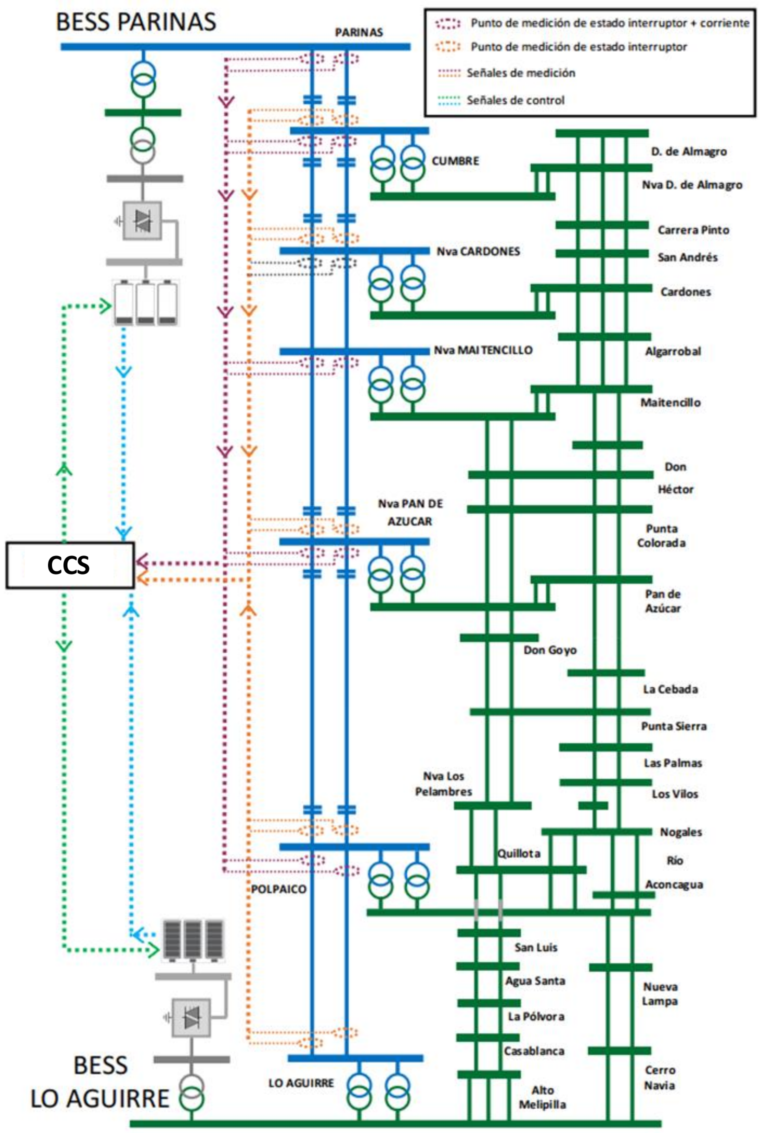
Modelación y Homologación de Instalaciones del SEN

Agosto de 2022

Gerencia de Operación

# Use Cases: Grid Booster Project

- Objective:
  - ✓ Increase transmission capacity in the 500 kV corridor by 500MW for 15 mins. (125MWh)
- 2x500 MVA BESS units (1,100 km apart)
- When a fault occurs at any section of the 500 kV line:
  - ✓ BESS in Parinas absorbs 500 MW & BESS in Lo Aguirre injects 500 MW
  - ✓ Alleviates the overload in the healthy line until redispatch
- Control System:
  - ✓ Requires redundant controls & communication systems
  - ✓ Fast communication between Central Control System (CCS) and local control units (PCU)



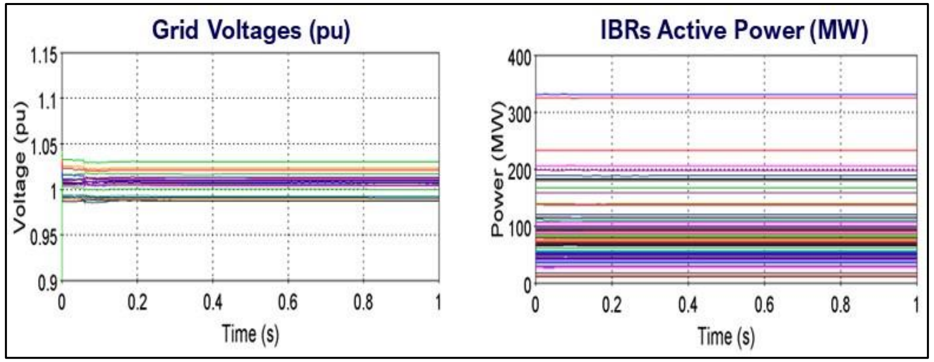


OAK RIDGE National Laboratory

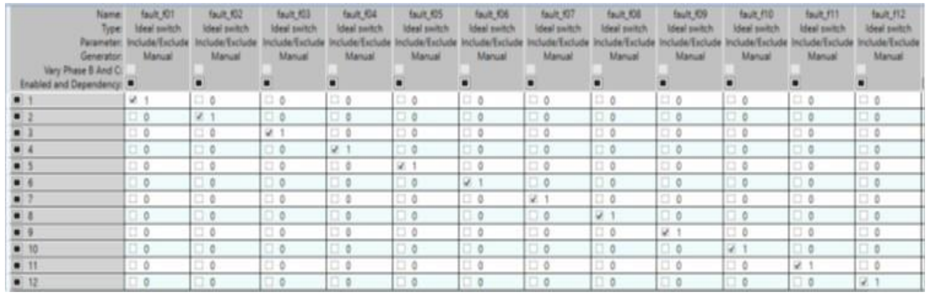
# Use Cases: Grid Booster Project

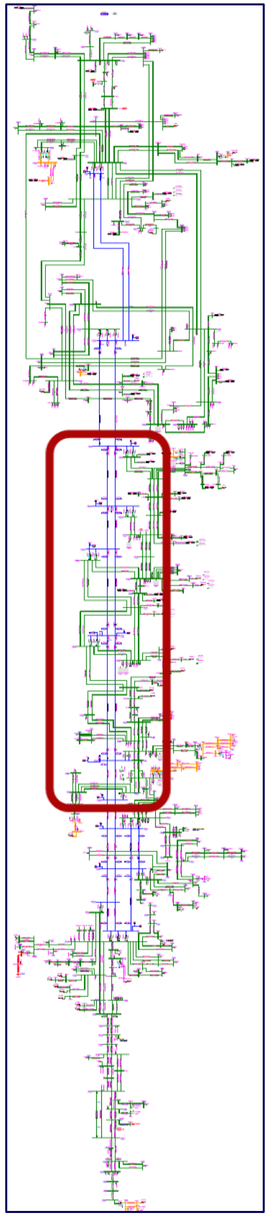
- **EMTP Model** :
  - ✓ Multiphase load-flow performed in EMTP® for automatic initialization
  - ✓ EMTP® Automated Simulation Toolbox for parallel simulations
  - ✓ Several grid configurations and parameter setpoints
- **Technical Requirements**
  - ✓ Dynamic reactive compensation at the GB BESS is required (power factor of 0.95)
  - ✓ Ramp rate of 50 MW/s provided FACTS (FRT) settings can be adjusted
  - ✓ If the FRT settings can't be changed, a ramp of 1000 MW/s is needed
  - ✓ No BESS short-term overload is required
  - ✓ Stable with 1x100MW module out of service (5 in total)
  - ✓ Capable to work under very low ESCR levels (<1.5)

**Steady-State Initialization**




**Automated Simulation Toolbox**





M. Agüero, J. Peralta, E. Quintana, V. Velar, A. Stepanov, H. Ashourian, J. Mahseredjian, R. Cárdenas, "**Virtual Transmission Solution Based on Battery Energy Storage Systems to Boost Transmission Capacity**", *Journal of Modern Power Systems and Clean Energy*, Mar. 2024.

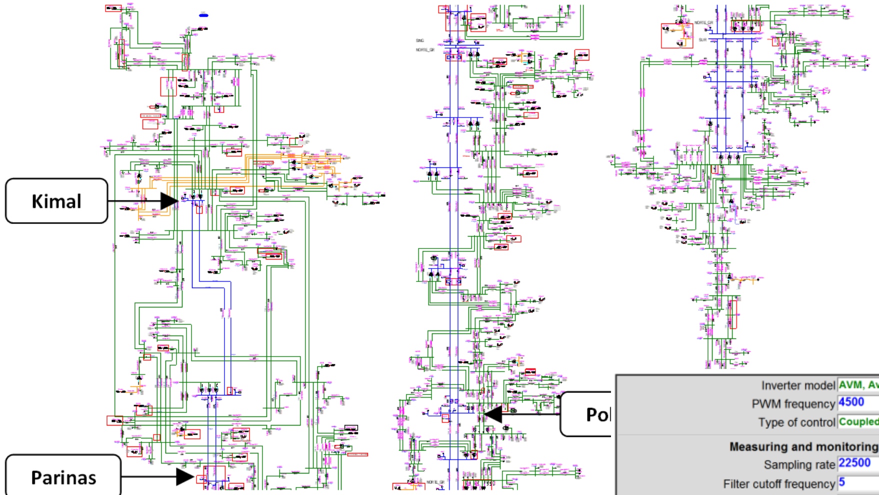
# Use Cases: Grid-Forming BESS Integration

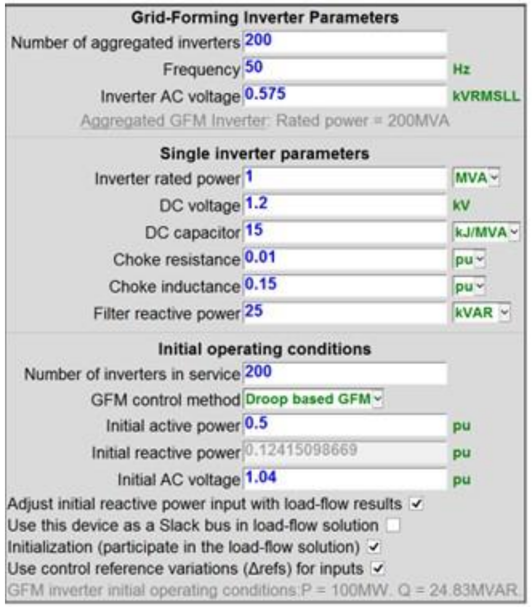
- Objective:
  - Model and assess the dynamic behavior of GFM IBRs in the Chilean grid using EMTP
  - Scenario with 70% of VRE (wind + solar)

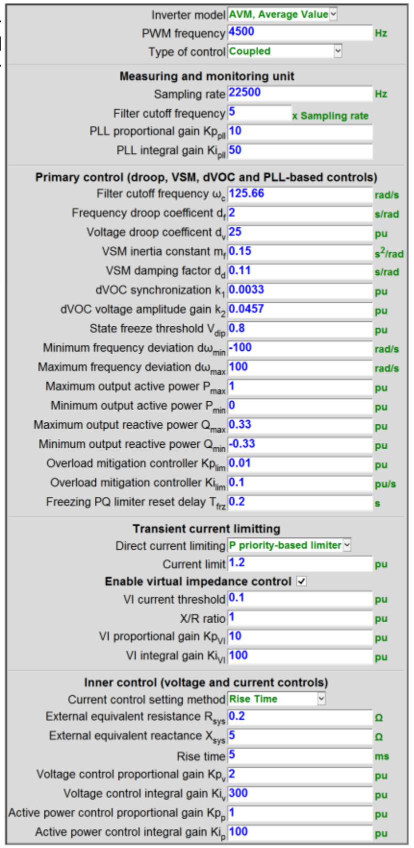
- 4x200 MVA GFM BESS units:
  - At locations with low ESCR (<1.5)
  - 3 GFM control method tested (Droop, VSM, dVOC)
  - GFM share 12-15%

- Critical contingencies :
  - Worst N-1 fault condition
  - Islanding of a weak grid
  - Loss of last SG in the island

D. Ramasubramanian, et al., "**A Universal Grid-forming Inverter Model and Simulation-based Characterization Across Timescales**," *56th Hawaii International Conference on System Sciences (HICSS)*, Maui, HI, USA, 2023.

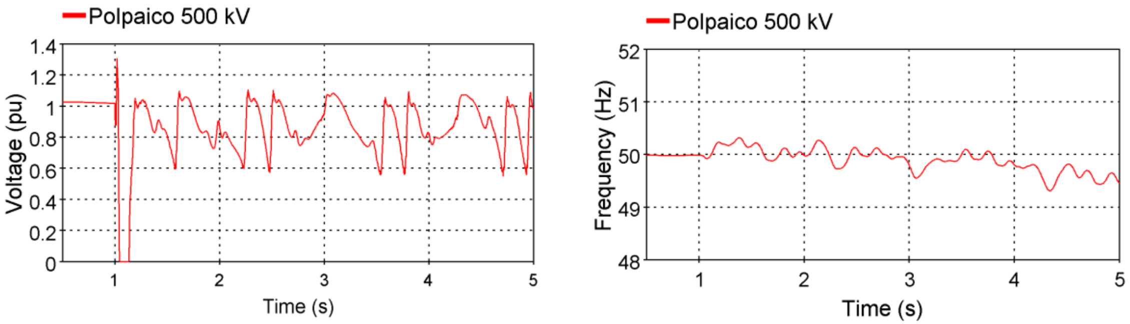


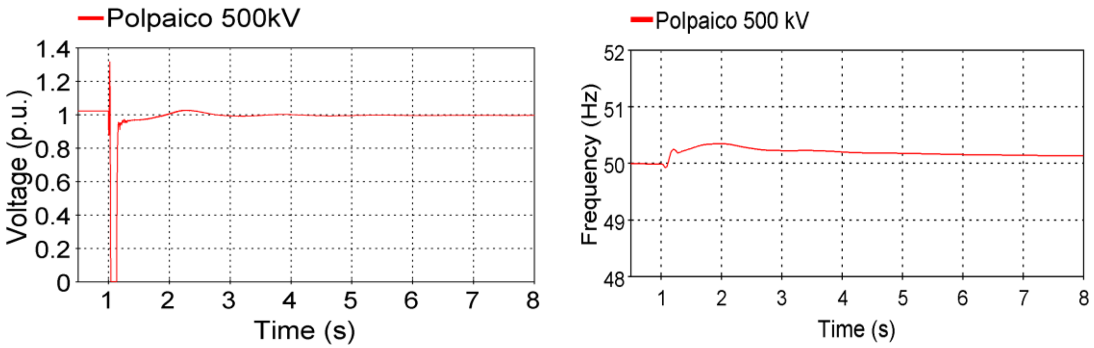



# Use Cases: Grid-Forming BESS Integration

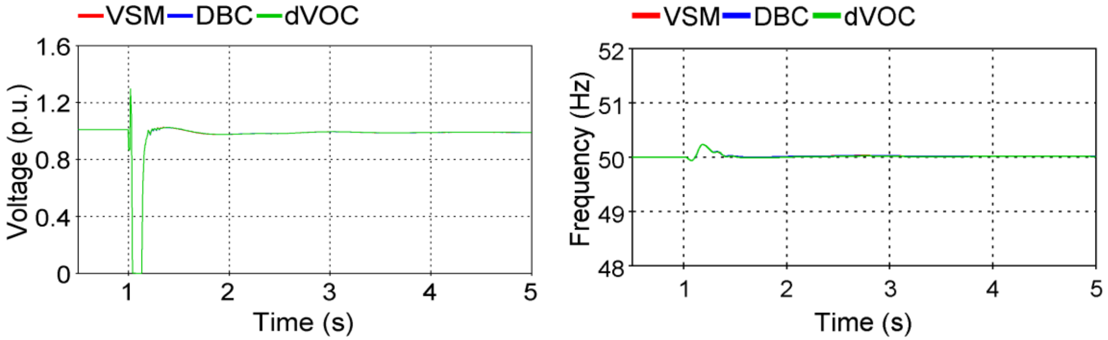
## 1. Base Case: Worst Fault



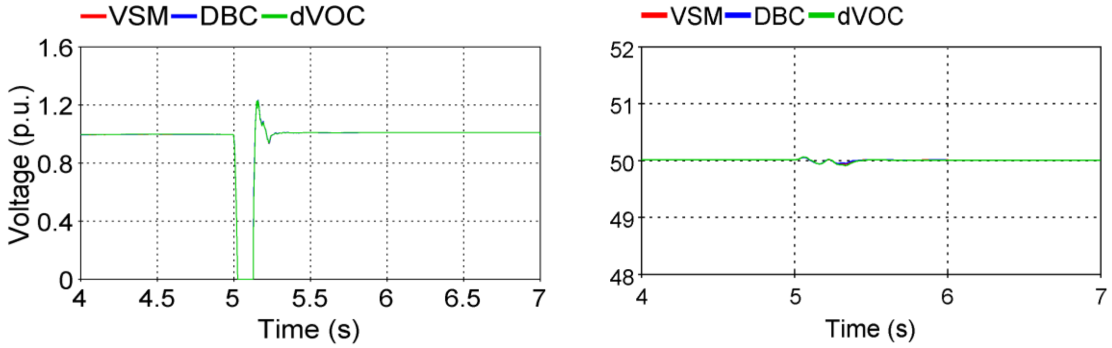

## 2. Base Case with SSCC: Worst Fault




## 3. GFM 4x100MW: Worst Fault

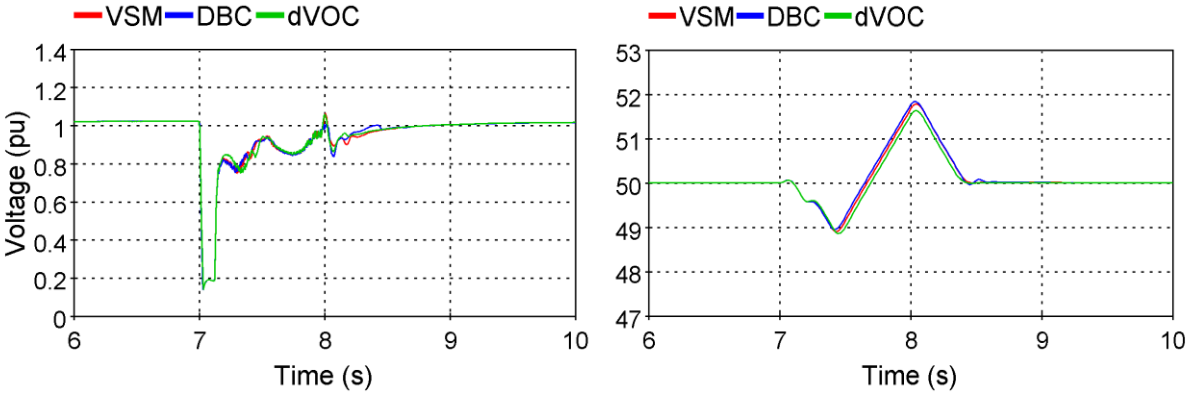



## 4. GFM 4x100MW: Islanding

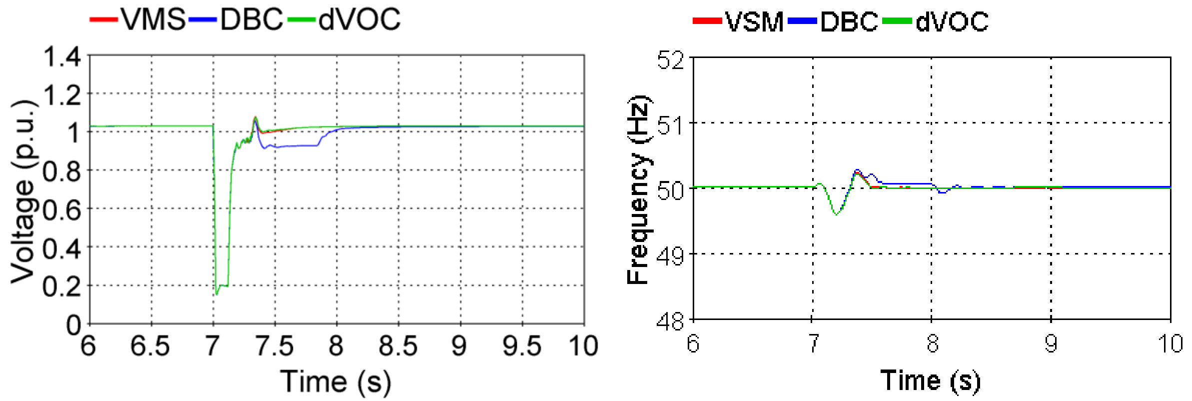


# Use Cases: Grid-Forming BESS Integration

5. Loss of Last SG (GFM)




6. Loss of Last SG (Increased GFM Cap.)



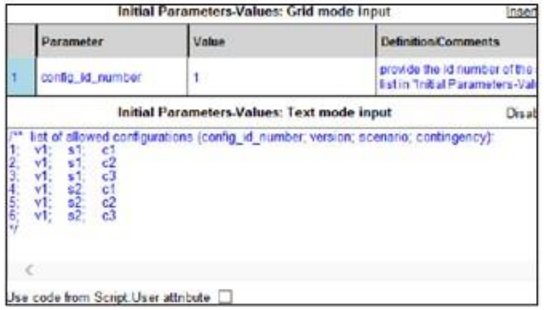

**Conclusions**:

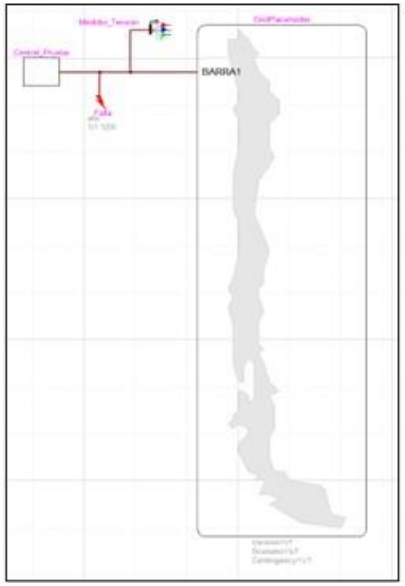
- GFM can positively impact the dynamic behavior and stability of the grid
- A minimum share of GFM was required (15%) to keep the grid stable under extreme events
- Additional research shall be conducted to assess protection coordination, and black-start capabilities

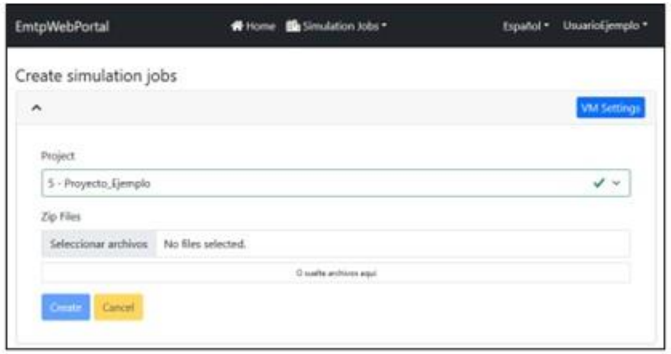
J. Peralta, V. Velar, E. Quintana, J. Mahseredjian, H. Gras, H. Ashourian, **"Dynamic Behavior of Grid-forming Inverters in Large-scale Low-strength Power Grids"**, *IEEE T&D Conference and Exposition, Anaheim, CA*, May 2024.

# Advanced EMT Applications

- **SCT-EMTP®: EMT Connection Tool in the cloud**
  - ✓ Detailed EMT model of the SEN for off-line analysis by market participants
  - ✓ Conducting EMT studies by protecting the IP rights of the models
  - ✓ Streamline the model verification during the connection process
  - ✓ Perform dynamic performance analysis, verify stability under low system strength conditions, assess impact of large projects (HVDC), etc.

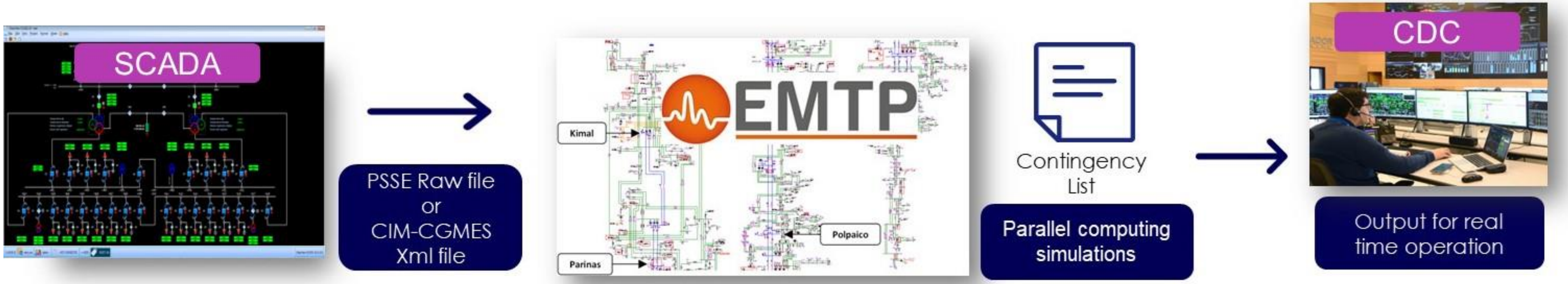




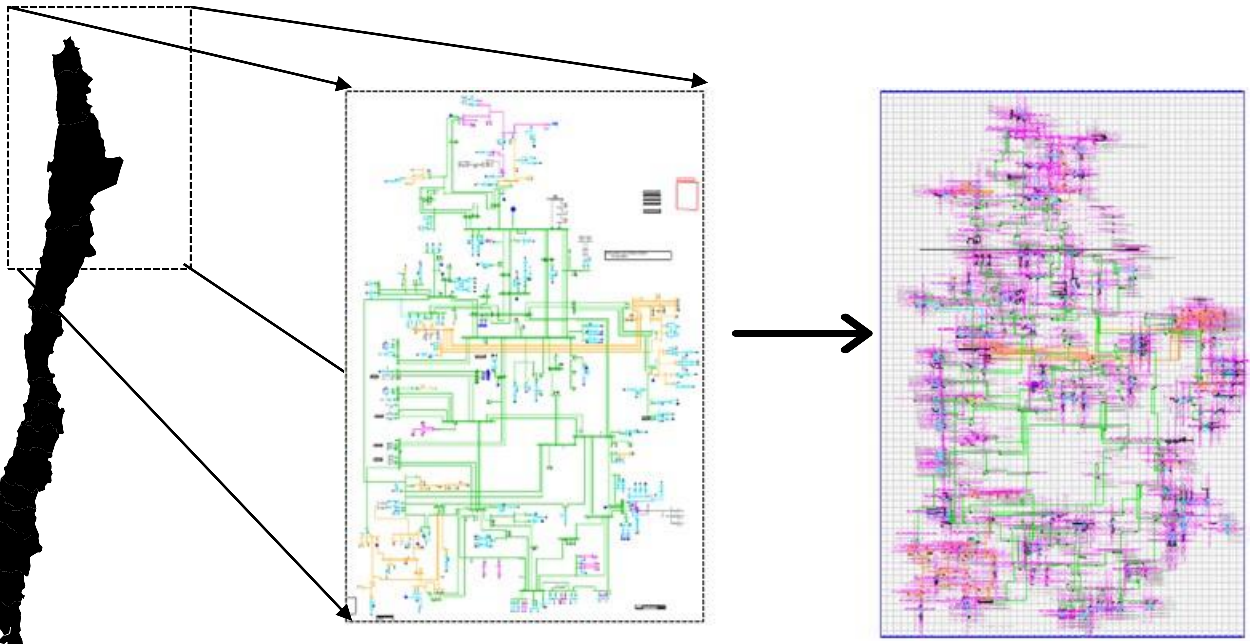
OAK RIDGE National Laboratory

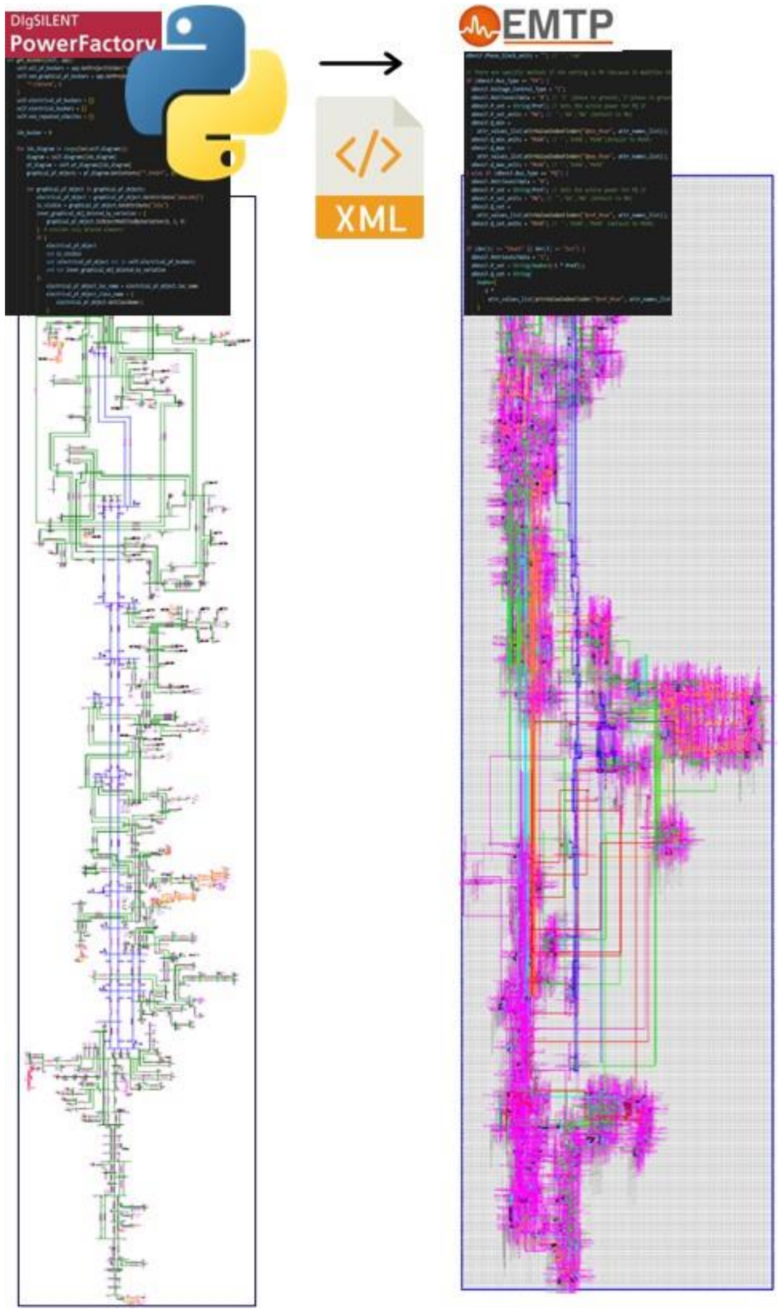
# Advanced EMT Applications

- **DSA-EMTP®: EMT Dynamic Security Assessment for the Control Room**
  - ✓ Detailed EMT model of the SEN for real-time applications
  - ✓ Expand grid model (1:1 representation)
  - ✓ EMT Dynamic Security/Stability Assessment for critical contingencies
  - ✓ Optimization with DLL models and parallel computing to achieve "near" real-time simulation
  - ✓ Interface with SCADA and PMUs
  - ✓ Automatic load-flow initialization from EMS state estimator
  - ✓ Additional module for off-line fault analysis



# Grid Model Conversion





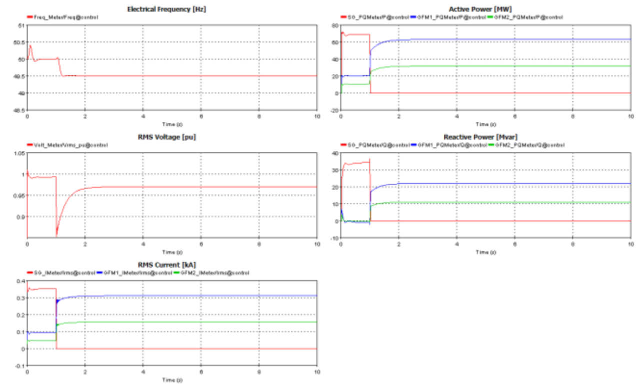

- ✓ One-to-one representation of full grid
- ✓ Automatic DB conversion to minimize errors (Python)
- ✓ Initially from Power Factory, in future from SCADA (DSA)
- ✓ Can be updated periodically
- ✓ Customized library for gens/FACTS/HVDC models (OEMs)

# Grid-Forming Requirements & Performance

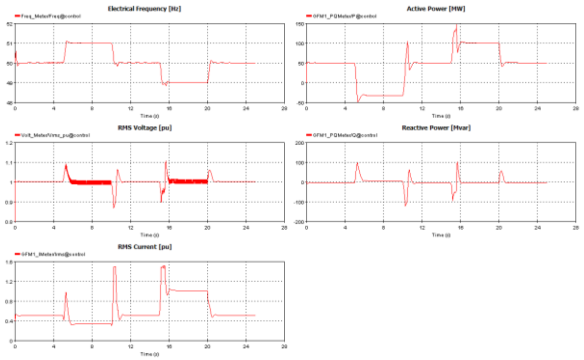
- ✓ Critical to ensure a reliable operation towards decarbonization
- ✓ Required for the deployment of the 4-6 GW of BESS by 2030
- ✓ Develop specs. and requirements for the Chilean Grid Code/Tenders
- ✓ Collaboration with G-PST (NREL/EPRI)
- ✓ Backed up by wide-area EMT analysis and RT/site tests
- ✓ Contemplates GFM model development (EMTP library)
- ✓ Validation against two OEM GFM models


**Model Validation – NERC & AEMO Test framework:**

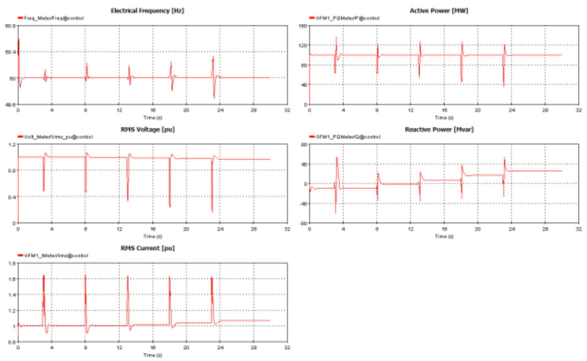
**Test 1**



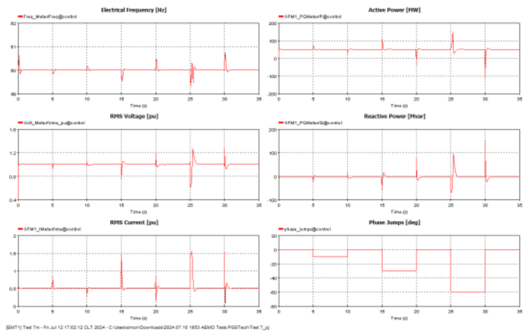
**Test 5**



**Test 6**



**Test 7**



# Lessons Learnt & Challenges

- Hard to engage MP to build EMT models (SCT access)
- Lack of standardization for the EMT models (DLLs)
- Automatic initialization (load-flow)
- Automation for data conversion is needed
- Lot of effort in homologation and validation
- Load model (currently constant impendence)
- Parallelization is critical to increase performance
- Balance level of detail  (high vs. low frequency phenomena)
- Priority for CEN is system behavior and interactions (AVM vs. DM, DC modeling)

# Summary

- Enabling technologies (FACTS/HVDC, BESS, GFM-IBR, GET, SSCC, etc.) are key to accelerate the energy transition.
- Advanced EMT tools are essential to assess the dynamic and transient behavior of (weak) grids dominated by power electronic IBRs.

# Next Steps

- SCT deployment with parallel EMTP version
- EMT model improvements (Load model)
- Start DSA-EMT development
- Further research on GFM performance in large grids (EMT)
  - ✓ Validate GFM against OEM models and test its behavior with 85% VRE
- Technical requirements for GFM technologies (EMT tests)

# Thanks for your attention

Dr. Jaime Peralta

Coordinador Electrico Nacional (CEN)

jaime.peralta@coordinador.cl

July 2024