Active and Localized Measurement of Grid Inertia

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Low Inertia Systems

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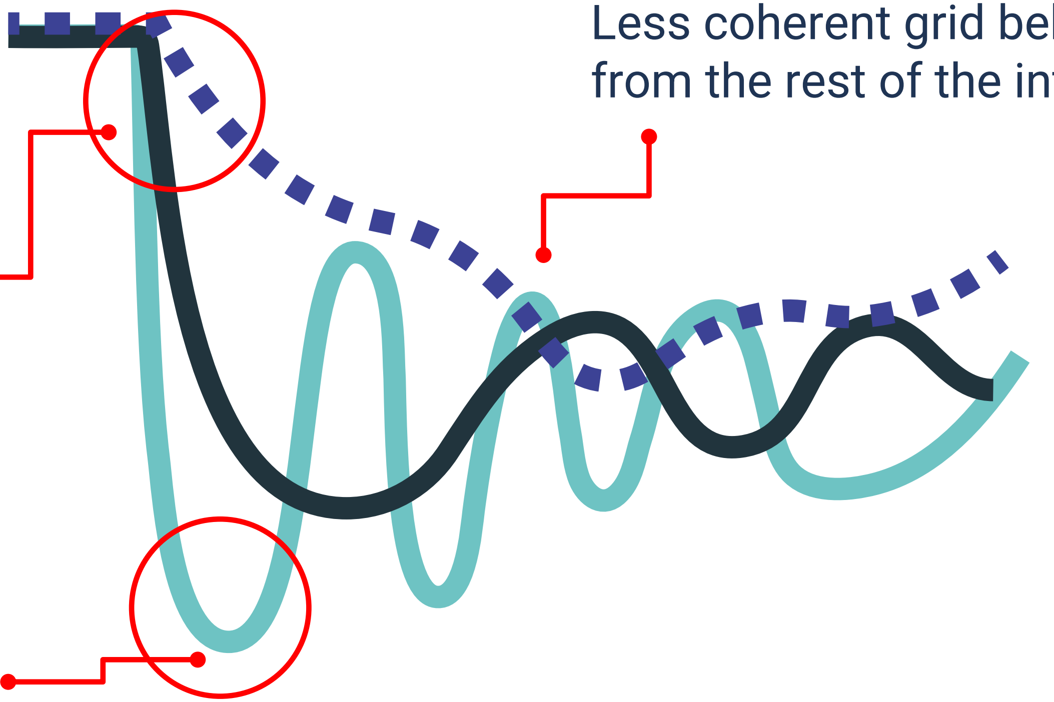
Frequency



High regional RoCoF can trigger anti-islanding relays, inducing cascading trips

Frequency can reach UFLS before regulation action timeframe

Less coherent grid behavior delays support from the rest of the interconnection

Why measure inertia?

Secure local stability

Protection responds to local, not systemwide conditions.

Either frequency nadir or RoCoF can trip protective relays.

→ ***Regional inertia monitoring reveals risk exposure to high local RoCoF.***

Understand system dynamics

Different physical phenomena contribute to Δf and df/dt :

- Rotational inertia
- Fast frequency response
- Governor response
- Load damping
- Network impedance coupling

→ ***Disaggregating contributions is necessary to understand and model the impact of contingencies.***

Support efficient grid planning

Planning dimensions include:

- Transmission upgrades to address both bulk power flow and security constraints
- Synchronous condensers
- Limiting RES interconnection

Strategic planning can help avoid expensive operational constraints.

→ ***Knowledge of regional inertia informs planning for optimal grid investments.***

Inertia monitoring comparing options.

No visibility of residual inertia

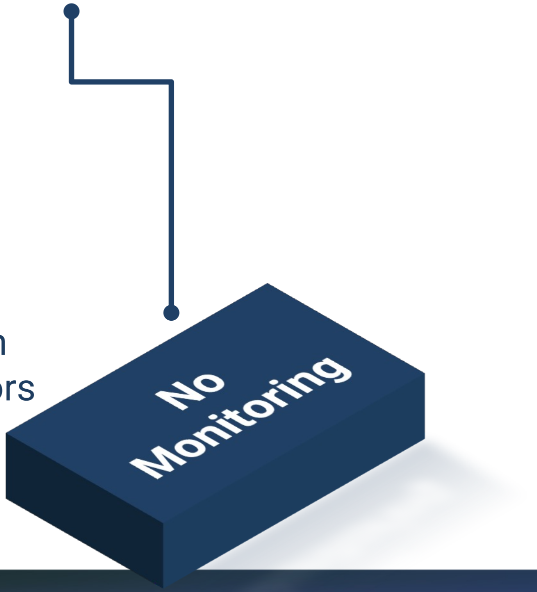
Total inertia not quantified or modelled

Inefficiencies in both system planning and operation

Over-procurement of synchronous condensers, FFR assets

RES and interconnection curtailment

Unnecessary constraints on variable loads and generators



Inertia monitoring comparing options.

Limited modelling and empirical validation of residual inertia

Uncertainty due to small sample size still forces worst-case assumptions, or implies risk

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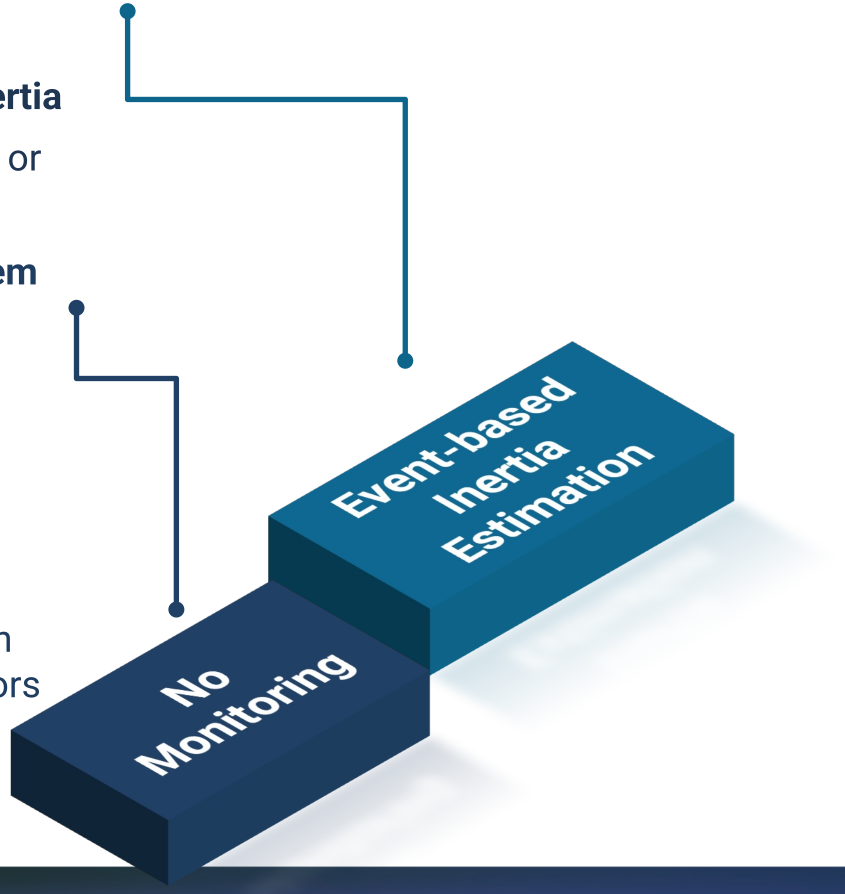

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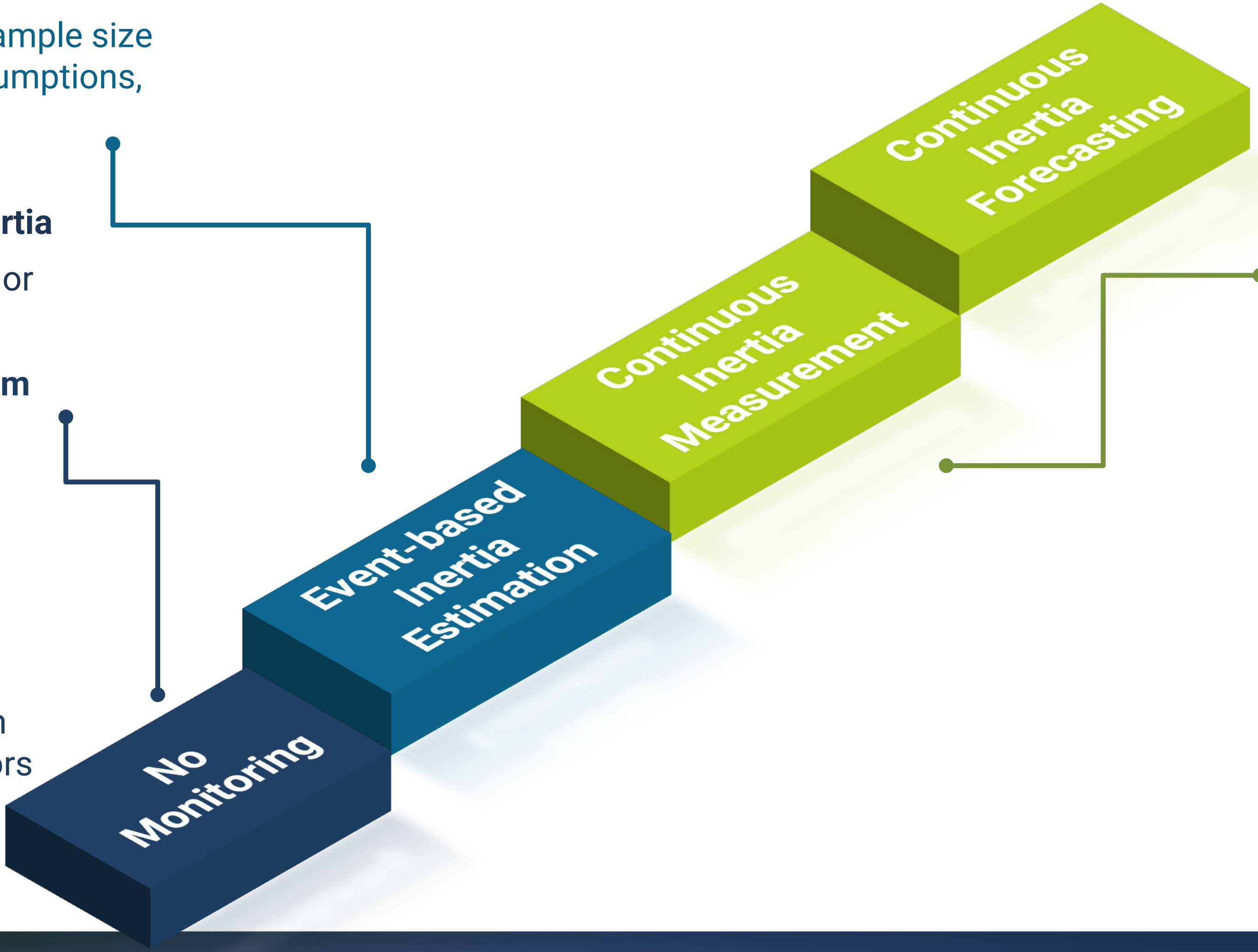

Clear understanding of residual inertia patterns

More precise system planning

Optimized operations

Strategies backed up by real-world data

Enables inertia procurement as an ancillary service for cost-effective grid stability

Financial optimization

Balancing asset investment with well-understood operational measures to ensure the most efficient allocation of resources

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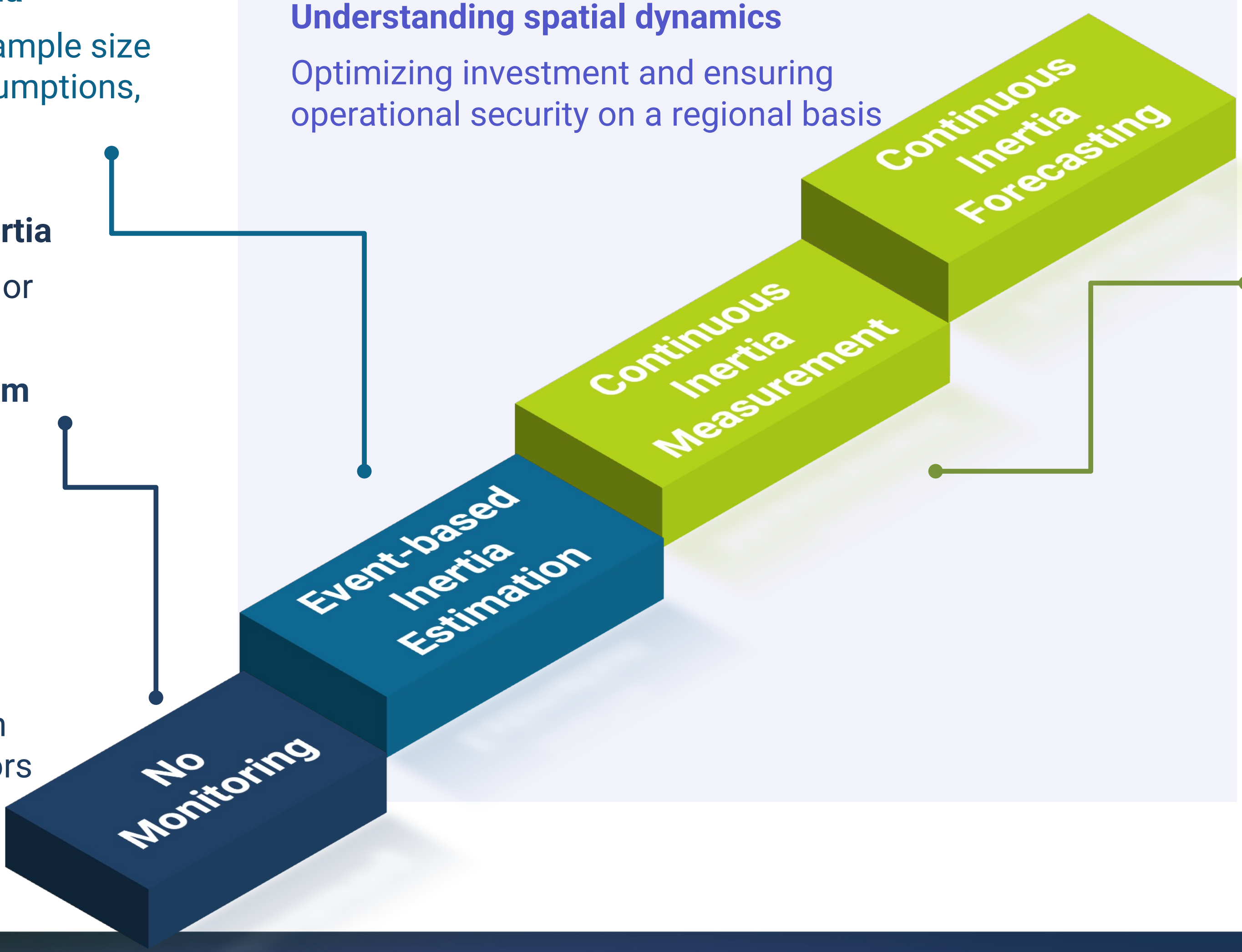
Location-specific inertia monitoring

Understanding spatial dynamics

Optimizing investment and ensuring operational security on a regional basis



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Inertia Measurement Methodology

Modulator[1] injects a small power signal

Grid frequency responds by < 1 mHz

XMUs[2] measure RoCoF across the system

PMUs measure the power across boundaries

The GridMetrix® platform computes inertia using the swing equation and advanced signal processing

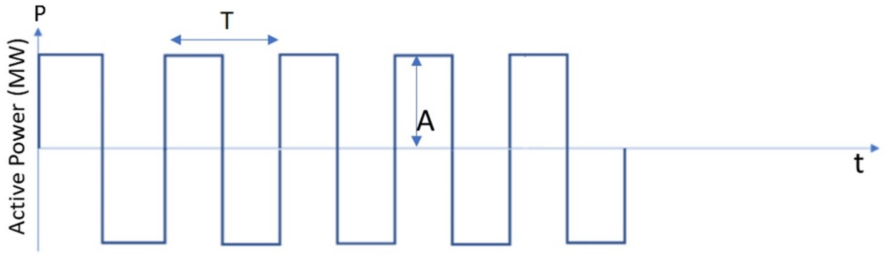
Inertia measurement available online and by API to the control center and planning teams

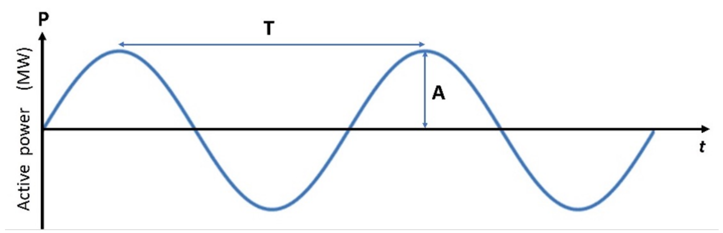
[1] *Modulator*: an asset such as a battery, ultracapacitor or load bank capable of generating a power signal

[2]. *XMU*: eXtensible Measurement Unit, Reactive Technologies' GPS synchronized accurate measurement unit.

Inertia Measurement Modulator

- MW scale **Ultracapacitor, BESS/ESS, IBR plant**
- Modulator must be designed to continuously generate a periodic active power modulation signal
  - Square wave and sine wave, for eliciting different aspects of response
  - Period of the modulation signal: typically in the range of 1 – 20 sec
  - Amplitude: 5 MW (10 MW peak-to-peak)
- Footprint: ~15m x 20m (+/- 20%)





XMU – Grid IoT.

Unlocking the power of edge computing.

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Powerful precision

- Adaptive sampling rate up to 48 kHz
- High resolution A/D conversion (16-bit)
- High Accuracy GPS time fleet sync (PPS)
- Adaptive DSP filtering (edge computing)

Clear communications

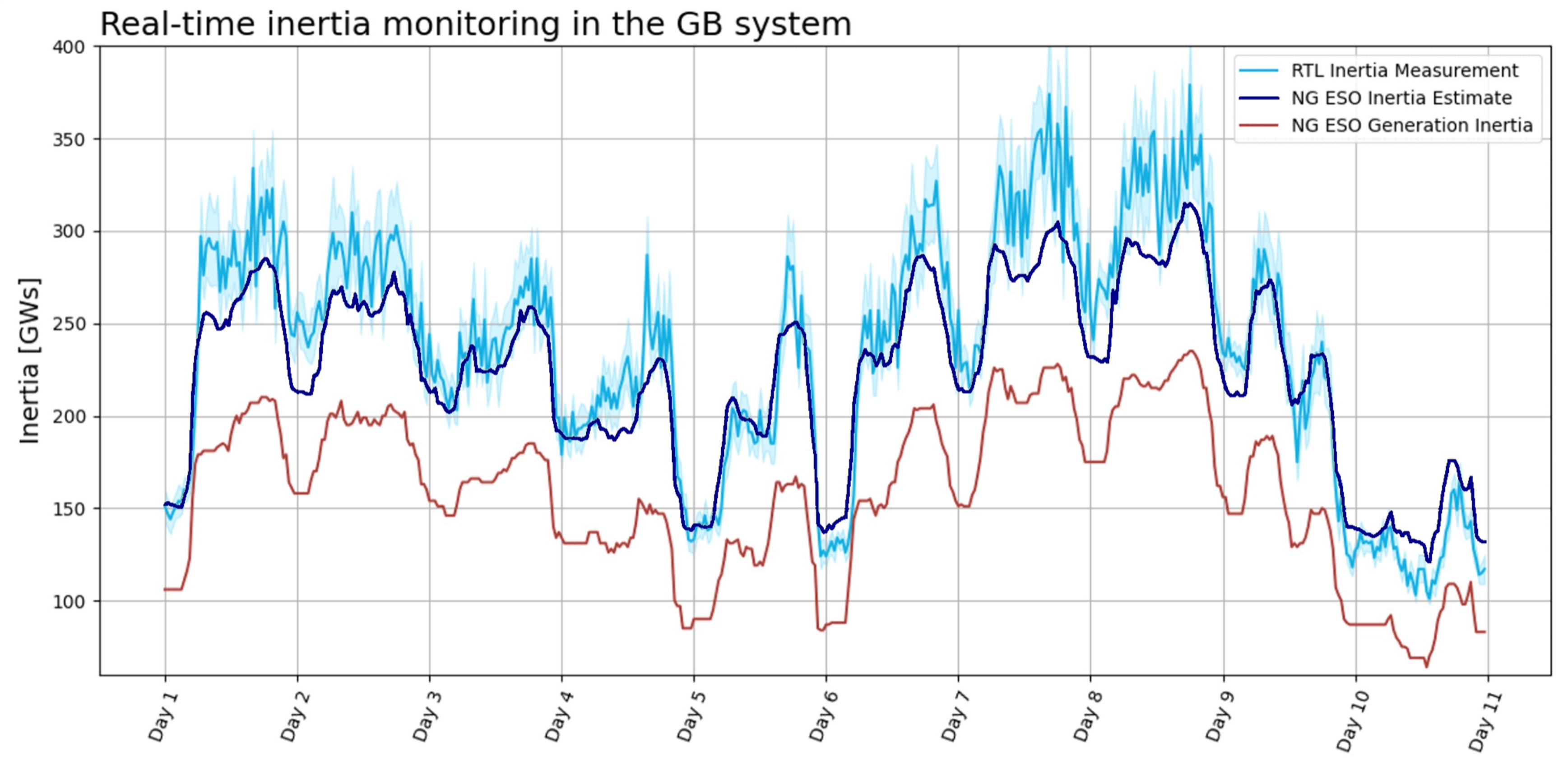
- Capable of streaming raw analog data
- Up to 120 Hz reporting rate
- Measuring frequency, RoCoF, oscillation parameters, power quality data
- Secure data encryption
- Integrates with GridMetrix cloud

Economical visibility of grid edge

- Hassle-free installation: plugged in at mains socket
- Remote device management

From models to direct measurement.

Hidden distribution grid inertia can account for **10-30%** of total system inertia.



Data from NESO Inertia Measurement commercial service, 2022

From models to direct measurement.

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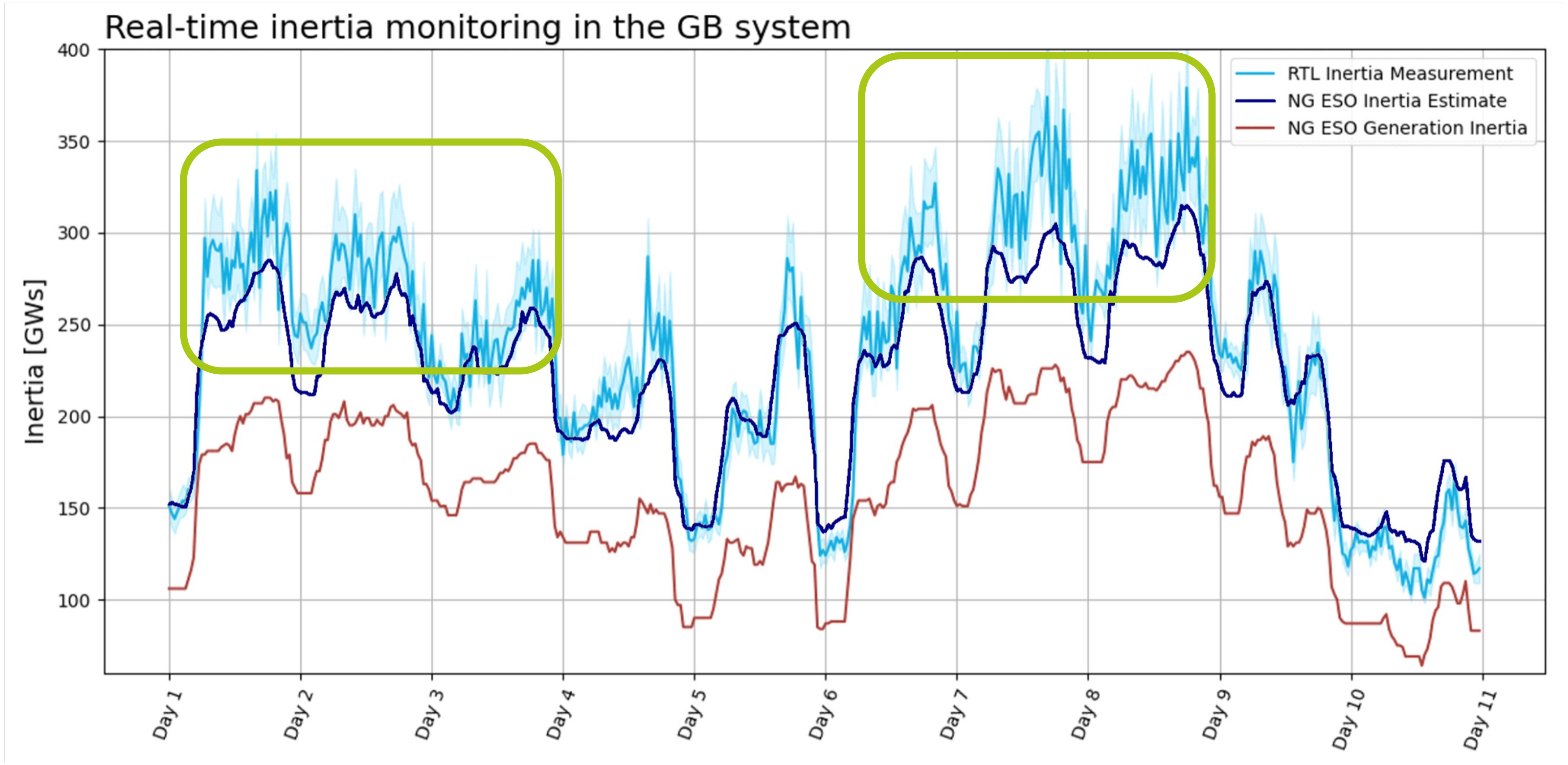
Most often, inertia is **underestimated**, showing potential for less balancing spend and RES curtailment.



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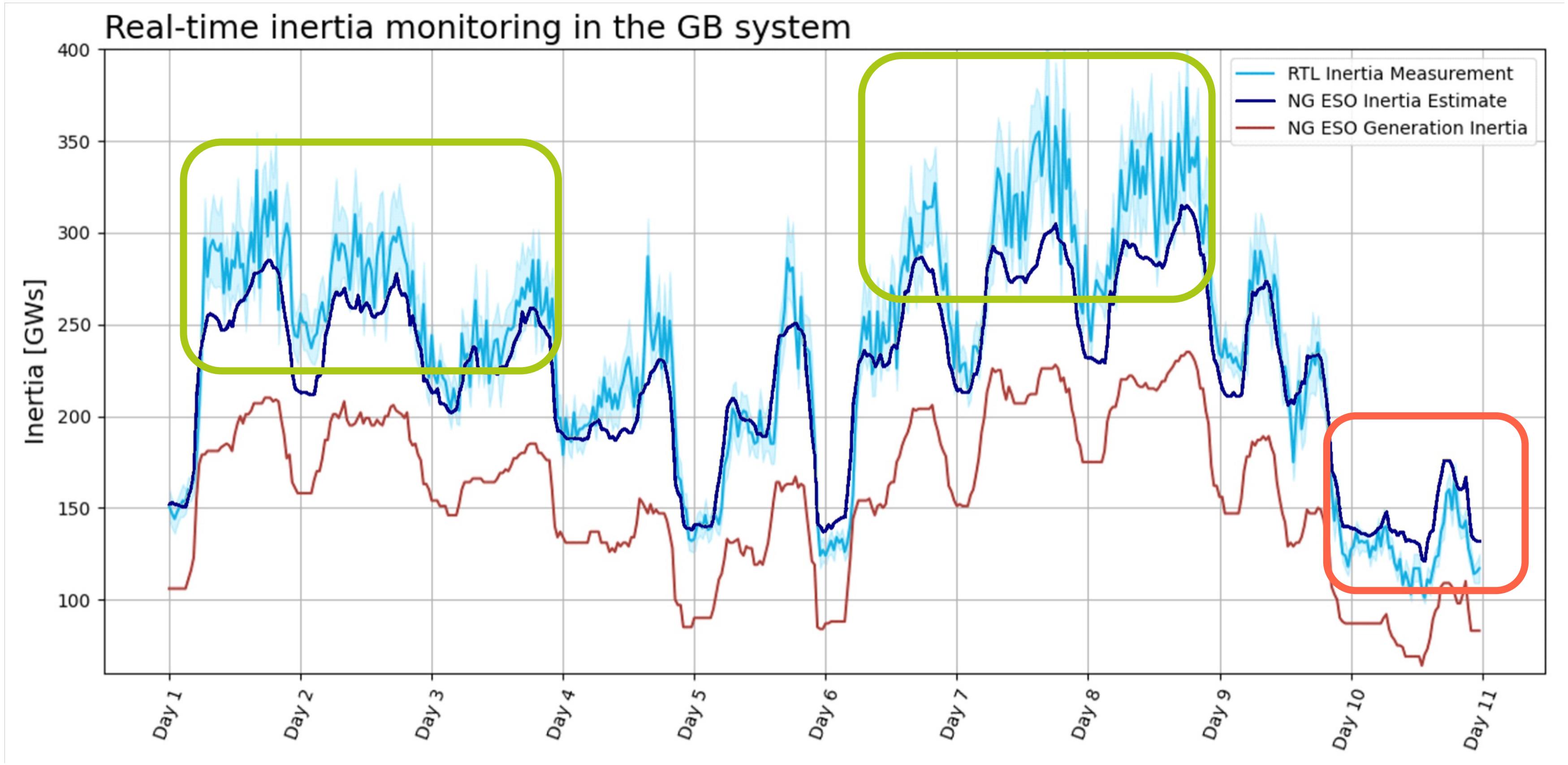
At times, inertia is **overestimated**, bearing higher security risk to system stability.



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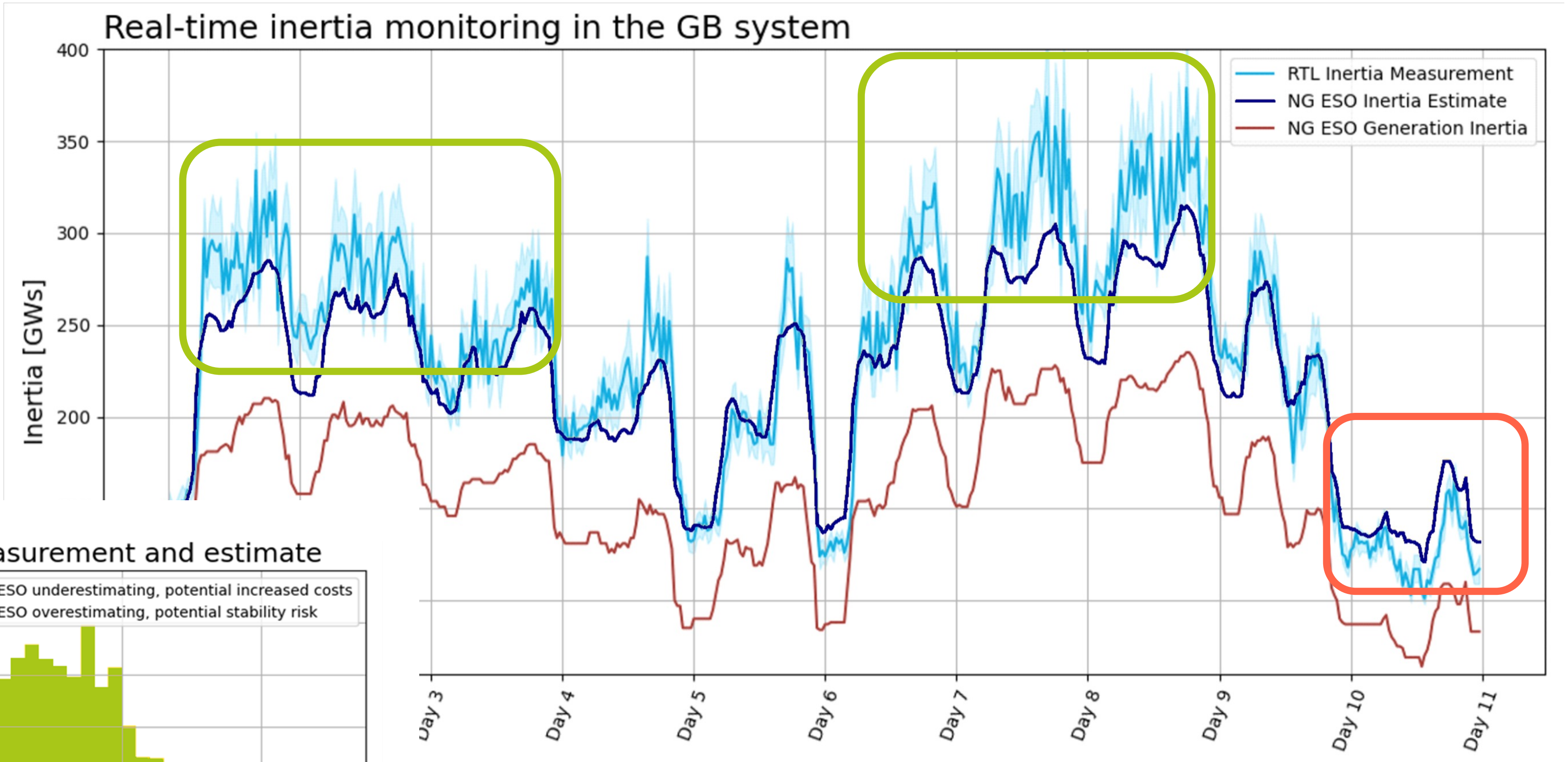
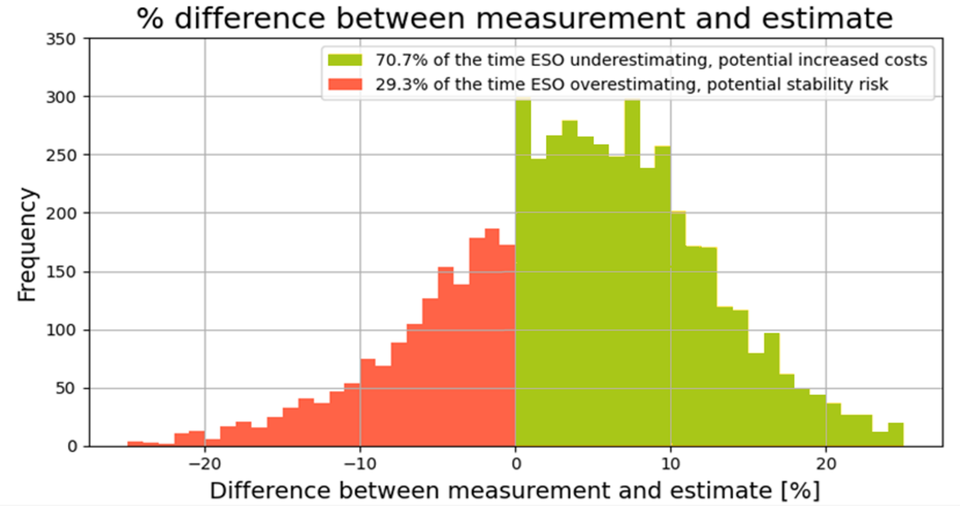
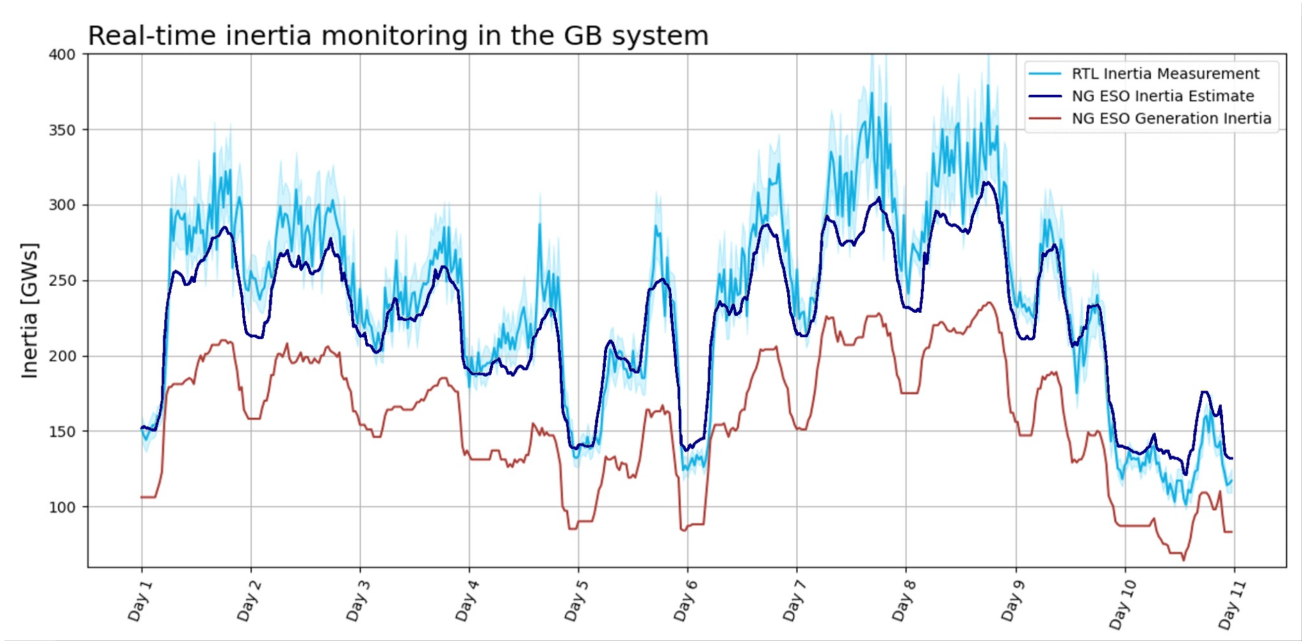
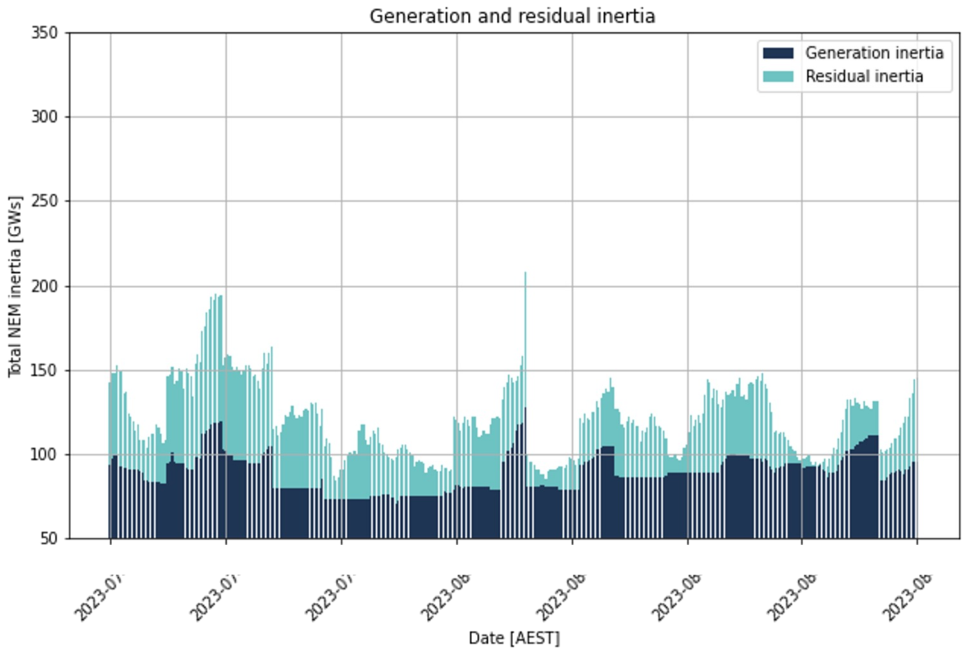


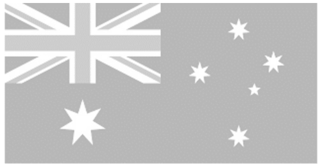


Data from NESO Inertia Measurement commercial service, 2022

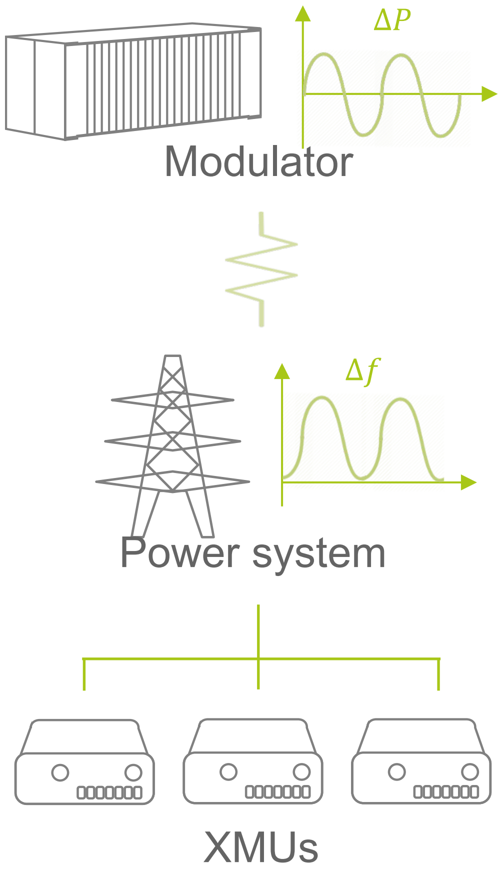
"Inertia measurement reveals the time-varying inertial contribution from demand and embedded generators"







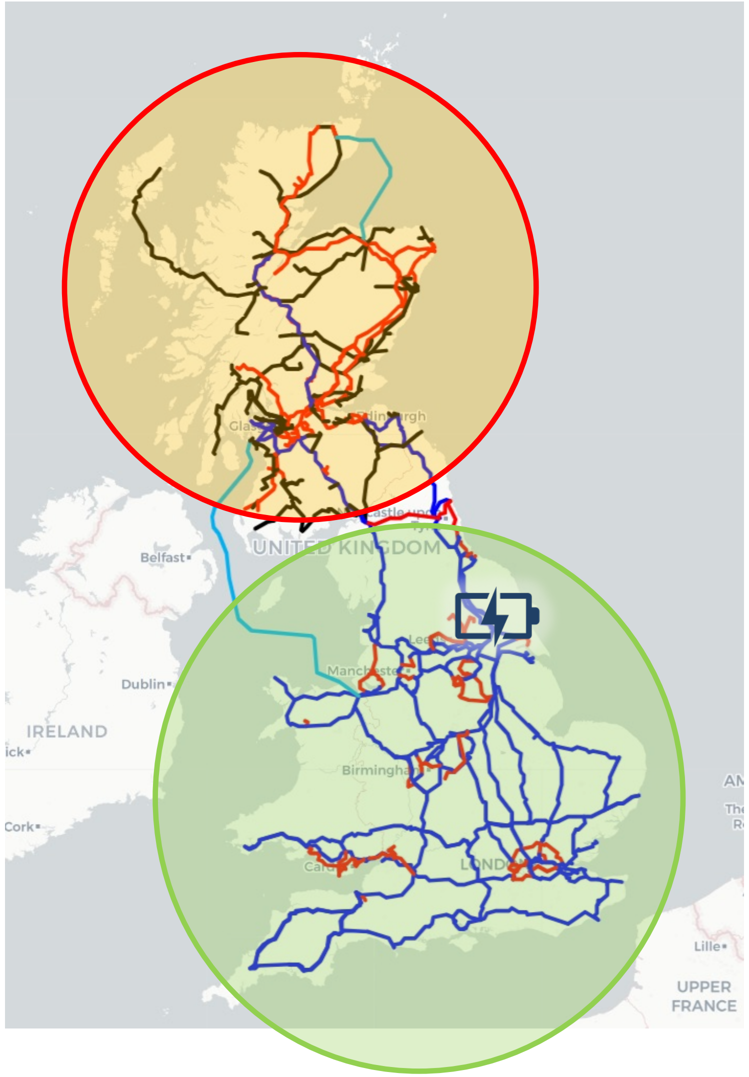
Great Britain project summary.



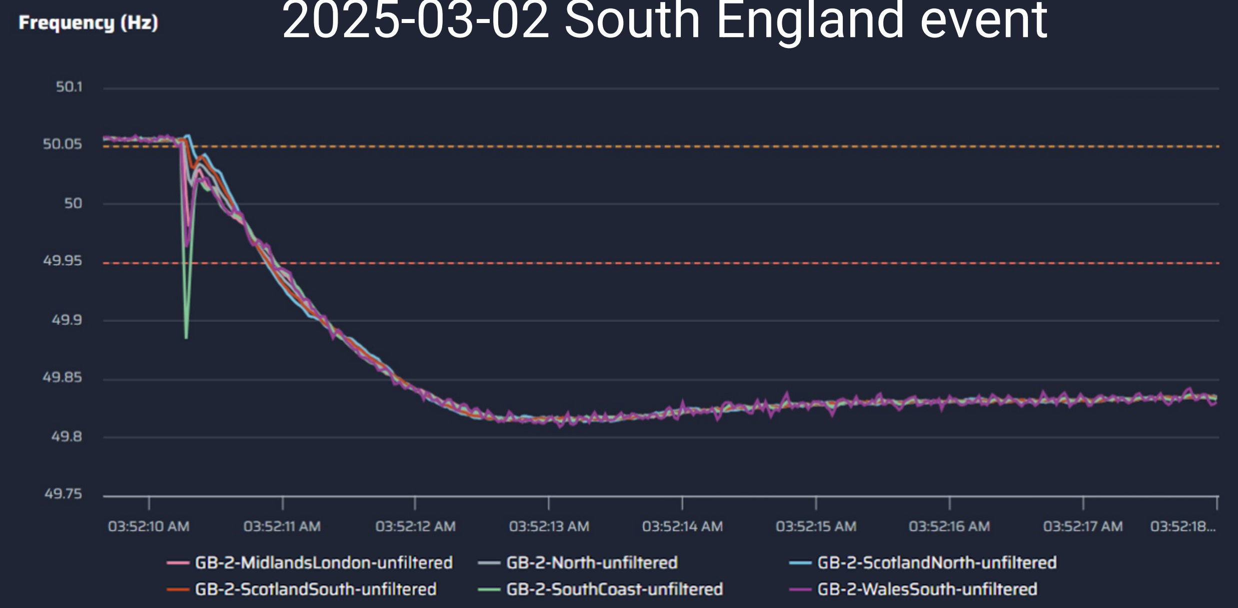
- Dedicated **super capacitor**
- **5 MW sine wave** signal

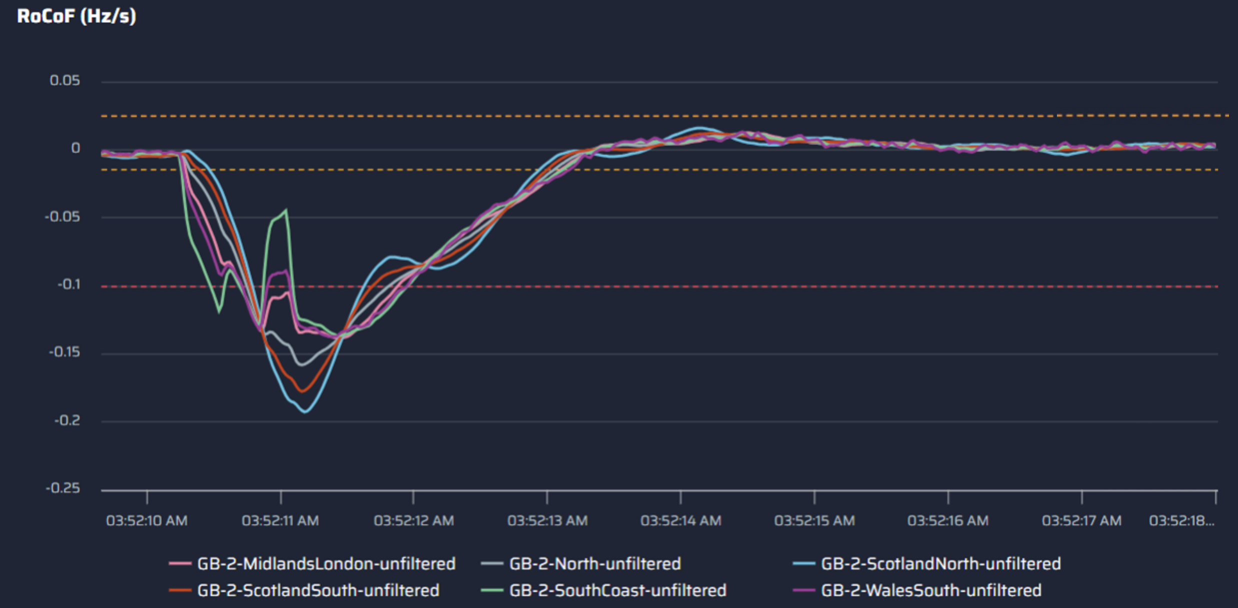
- Approx. **30 GW** of demand
- Approx. **50 %** of RES penetration
- Approx. **100-350 GWs** of inertia

- **40 XMUs** deployed across GB



2025-03-02 South England event





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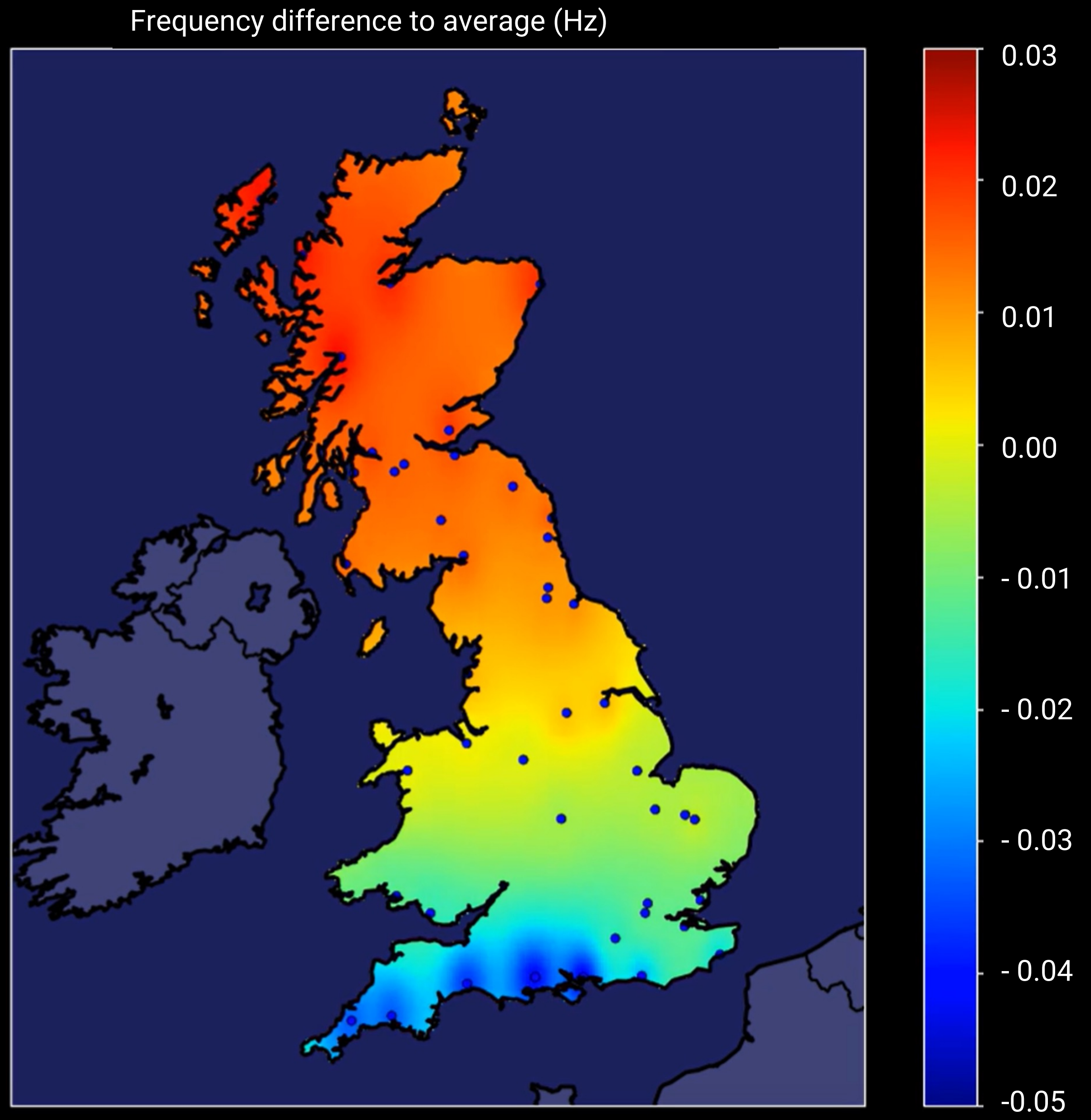
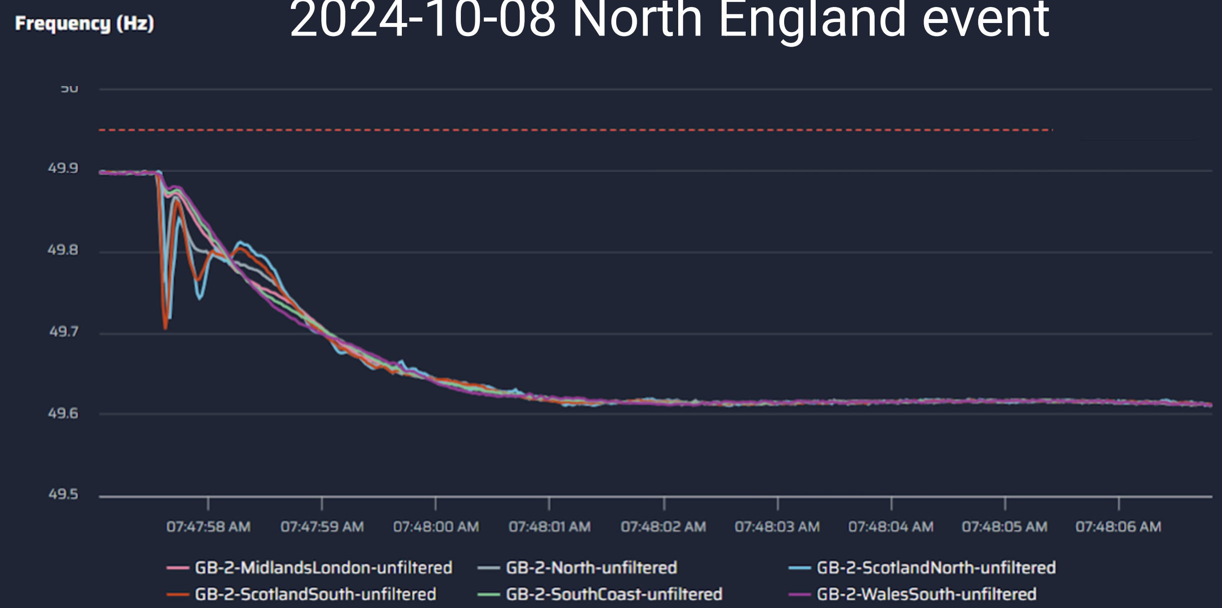
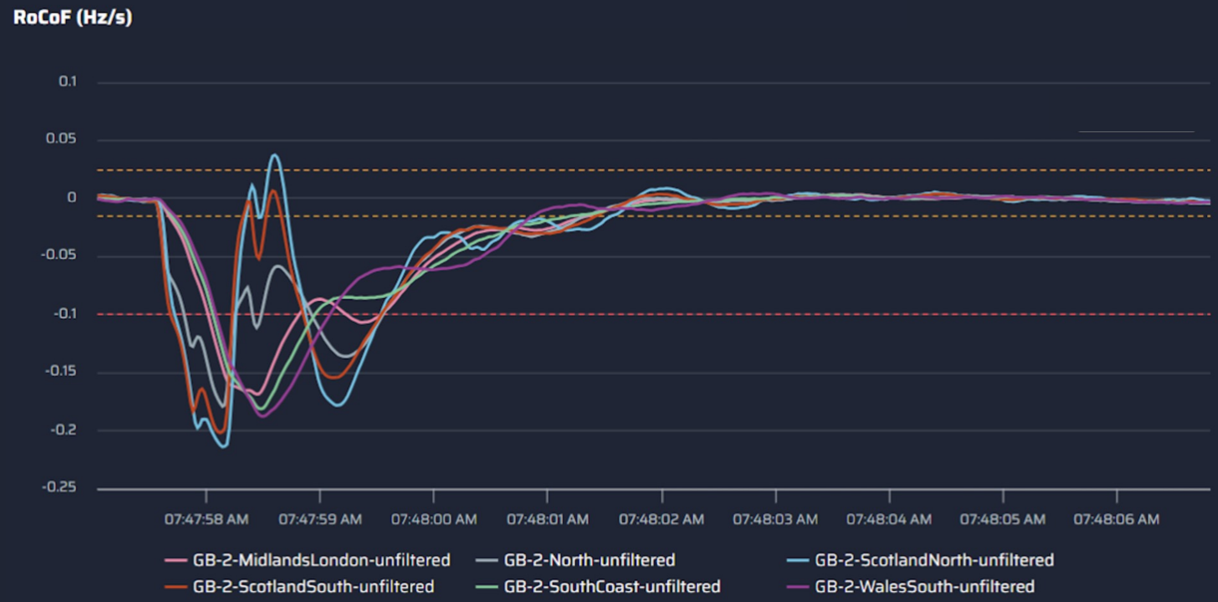
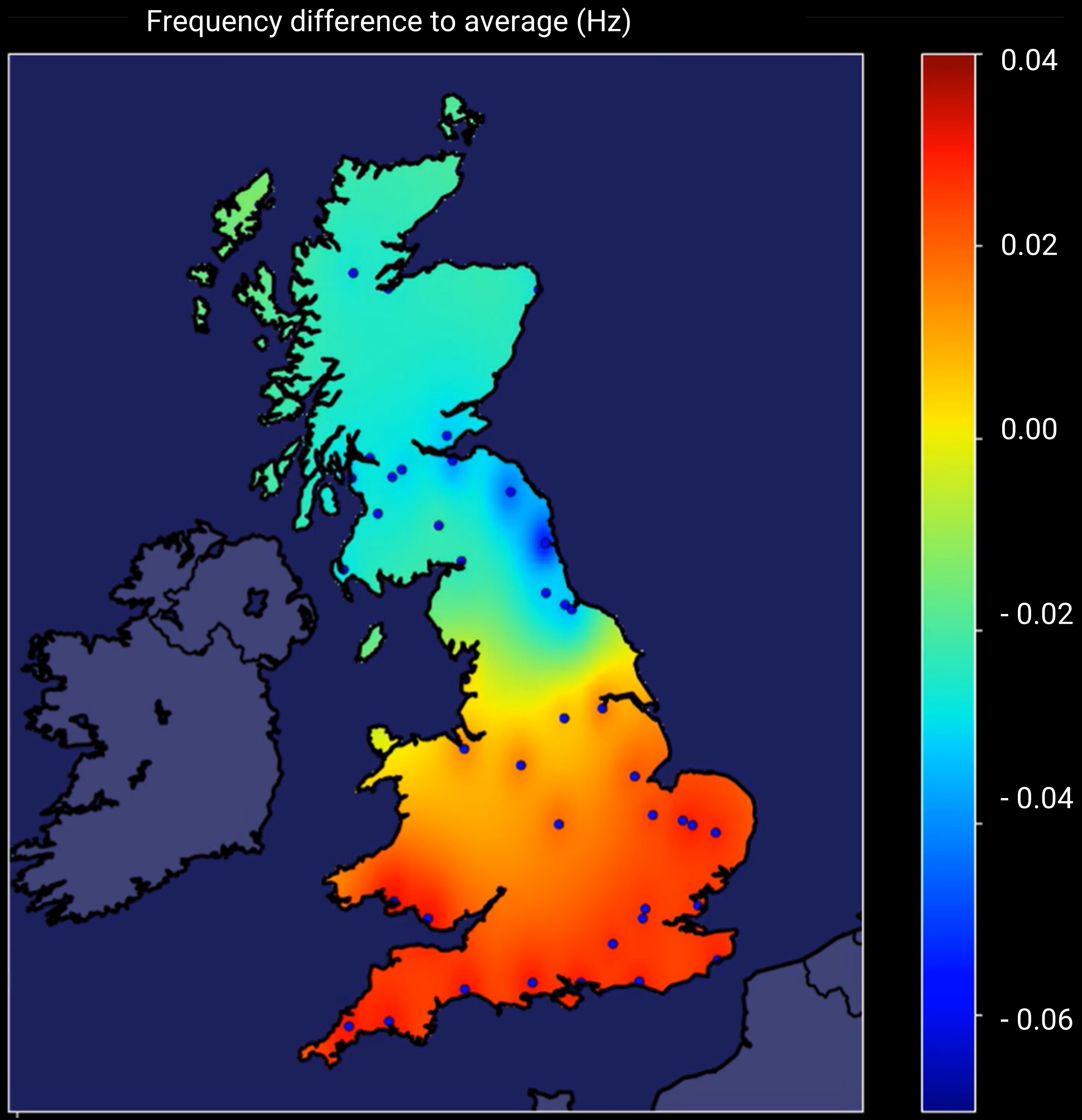


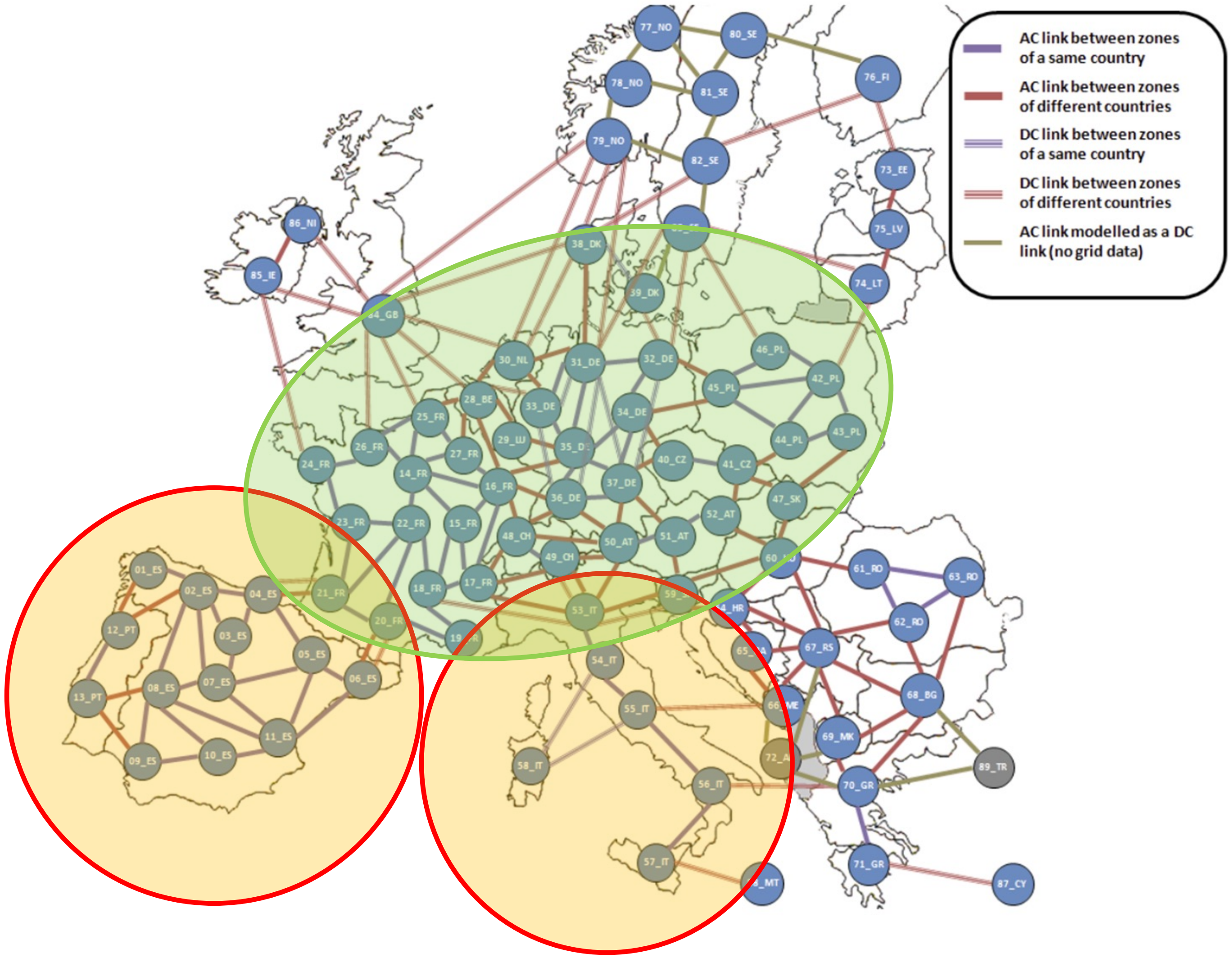
2024-10-08 North England event



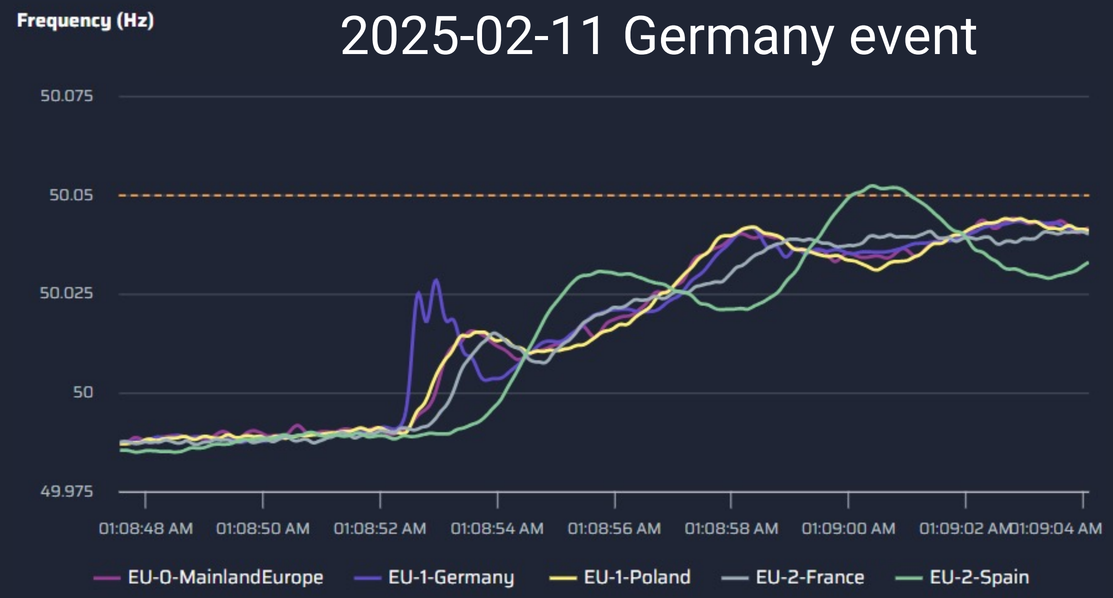


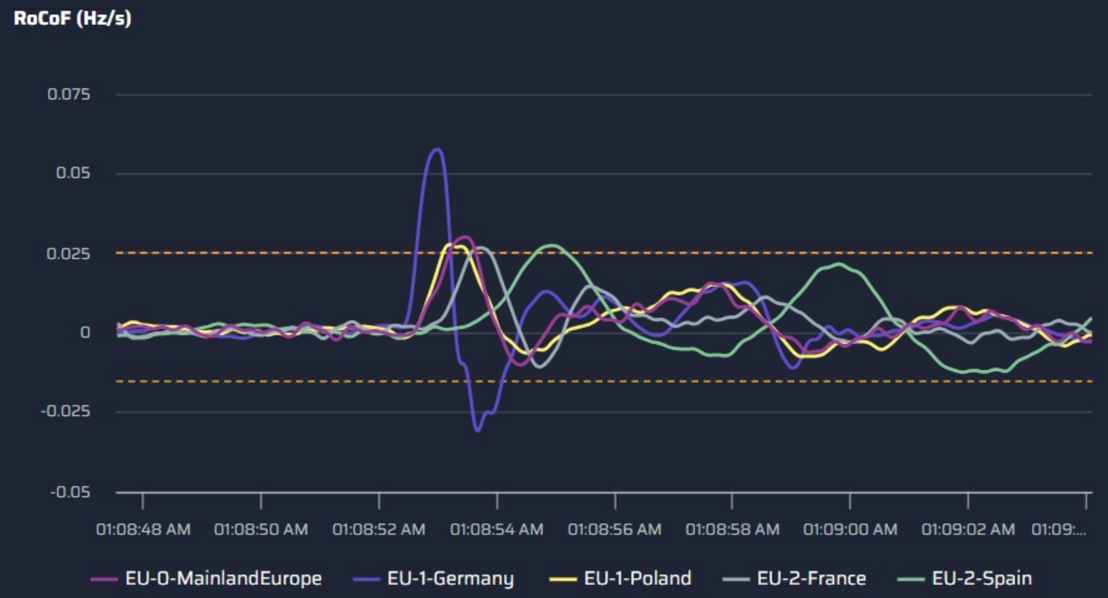


ENTSO-E network.

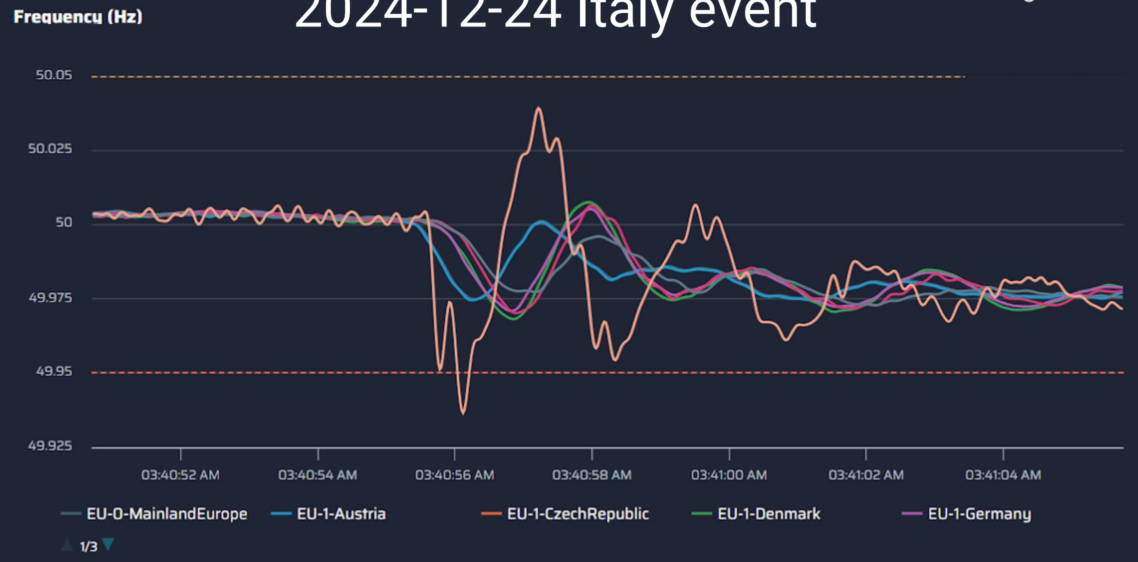


2025-02-11 Germany event

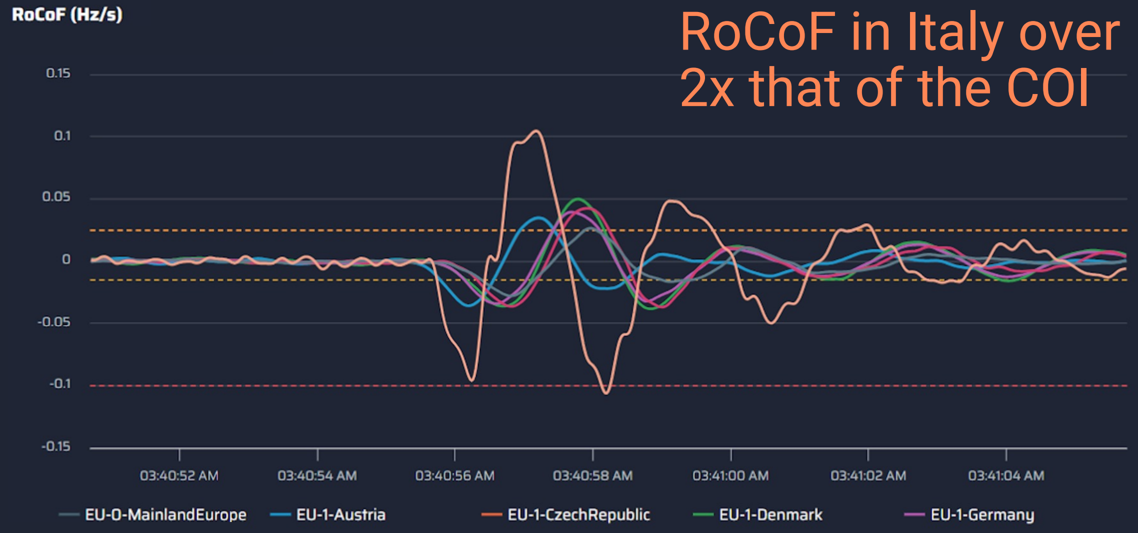




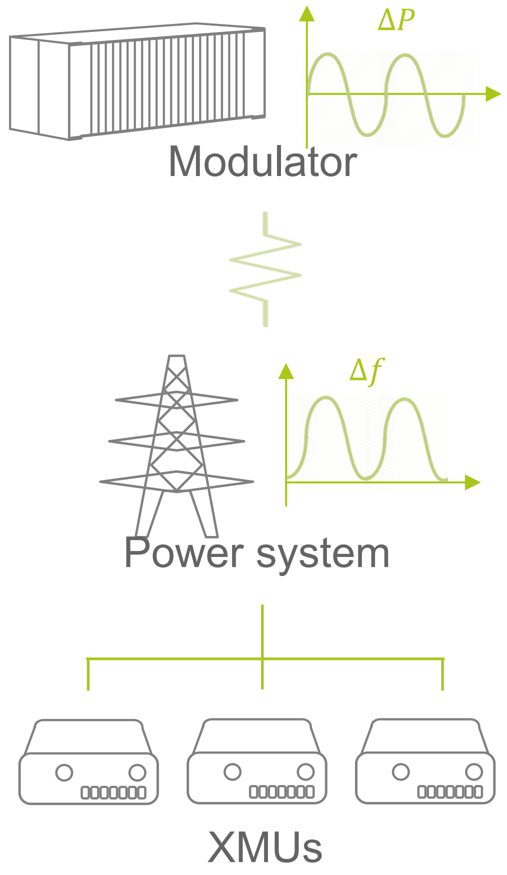
2024-12-24 Italy event



RoCoF in Italy over 2x that of the COI



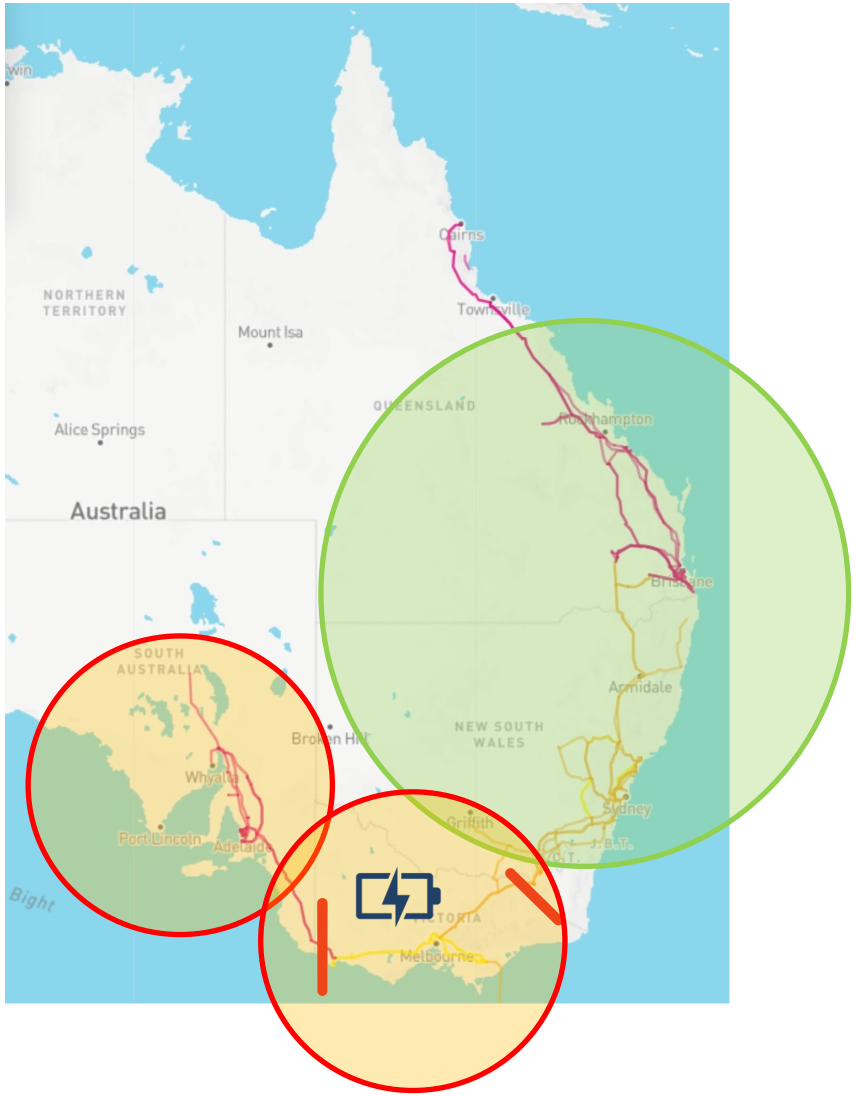
Australia project **summary.**



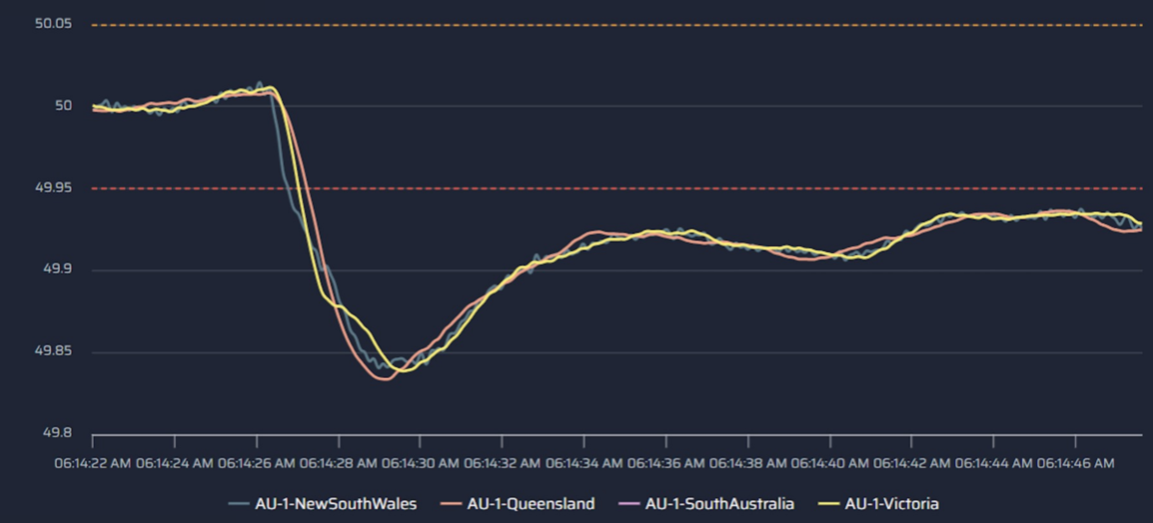
- Integrated with **VBB** (300MW BESS)
- **5 MW sine wave** signal

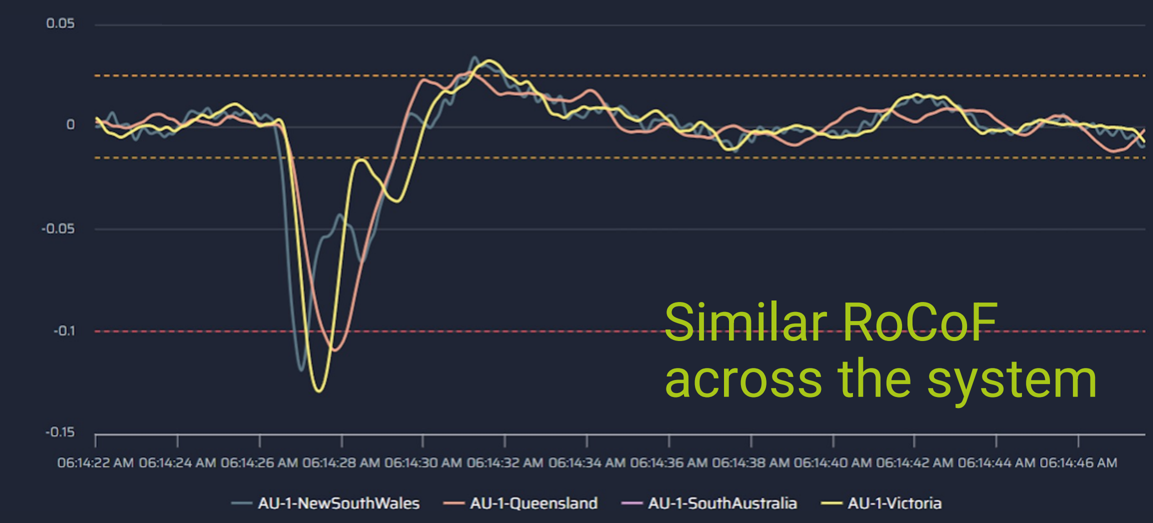
- Approx. **10 GW** of demand
- Approx. **40 %** of RES penetration
- Approx. **100-200 GWs** of inertia
- **3 regions** (South Australia, Victoria, New South Wales + Queensland)

- **47 XMUs** deployed across the NEM



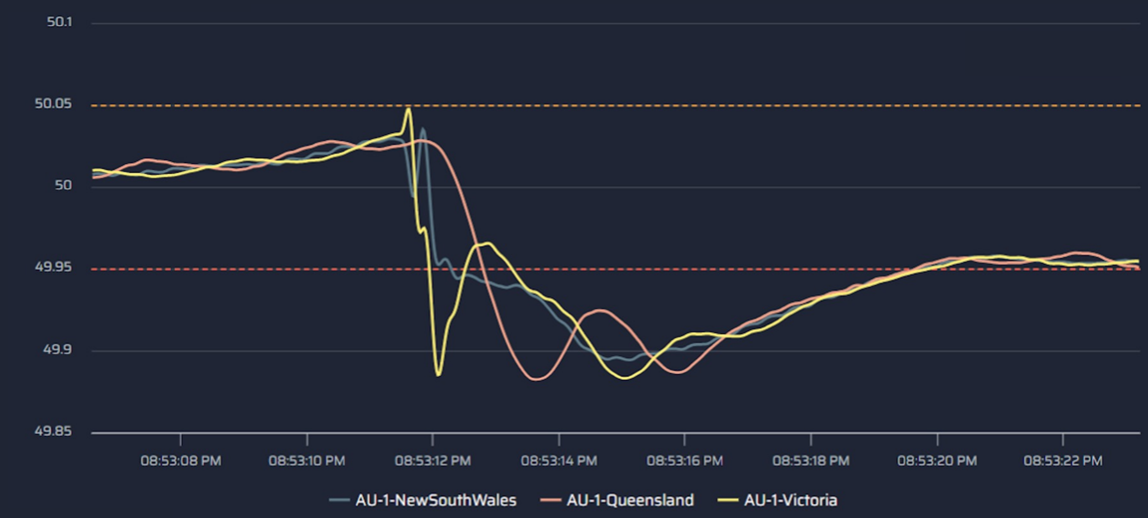
2025-03-05 NSW event

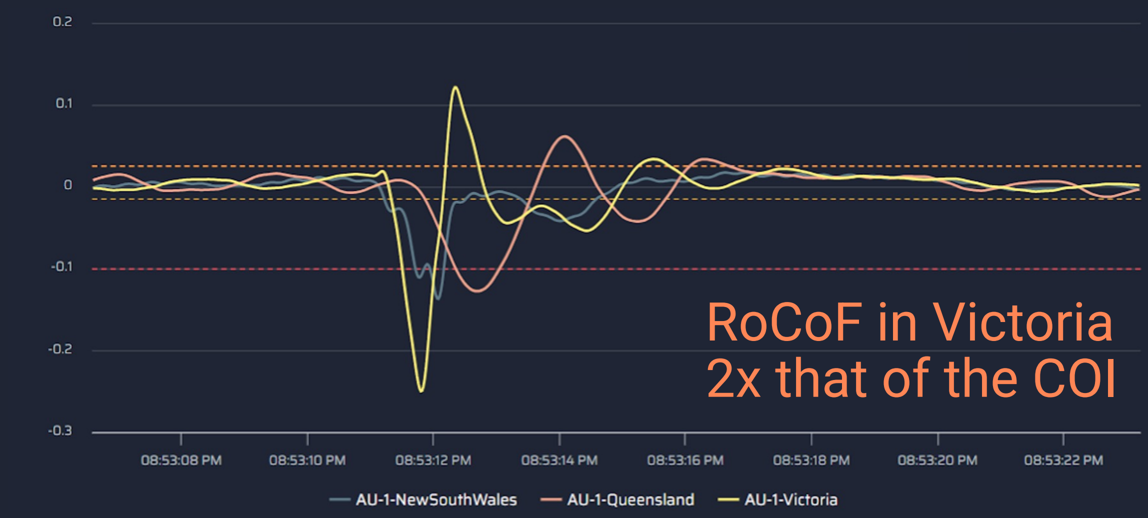




Similar RoCoF
across the system

2023-07-08 VIC event



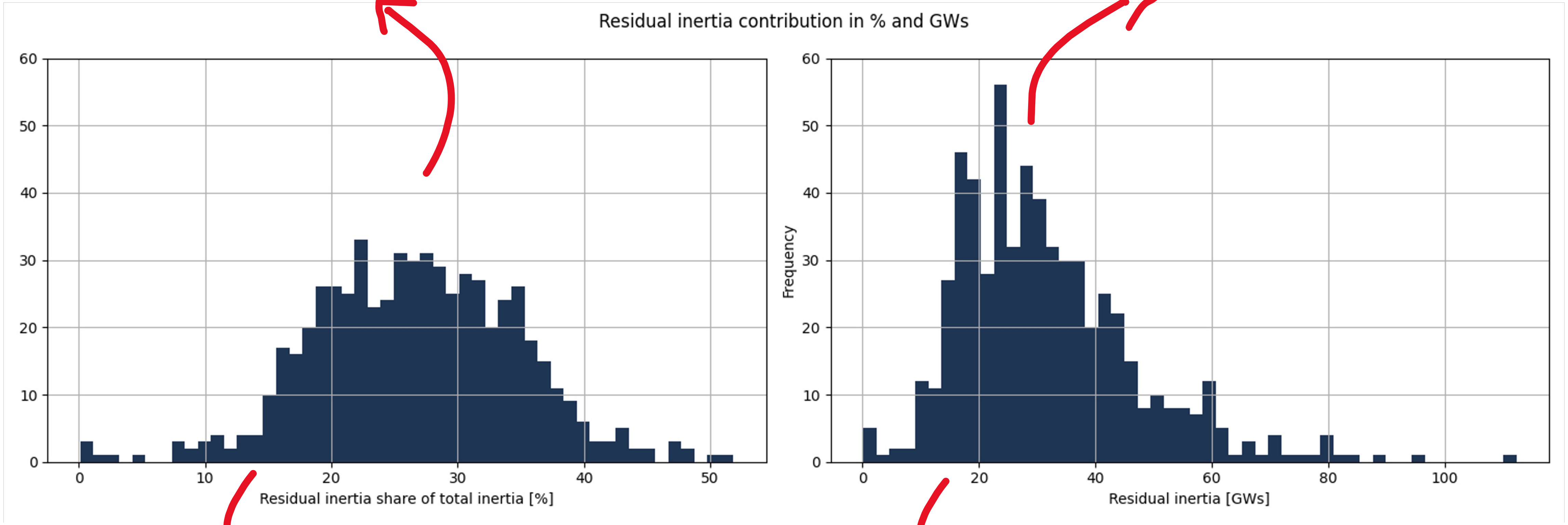


RoCoF in Victoria
2x that of the COI

Residual Inertia in the Australian NEM.

On average 27% of the inertia is "hidden"

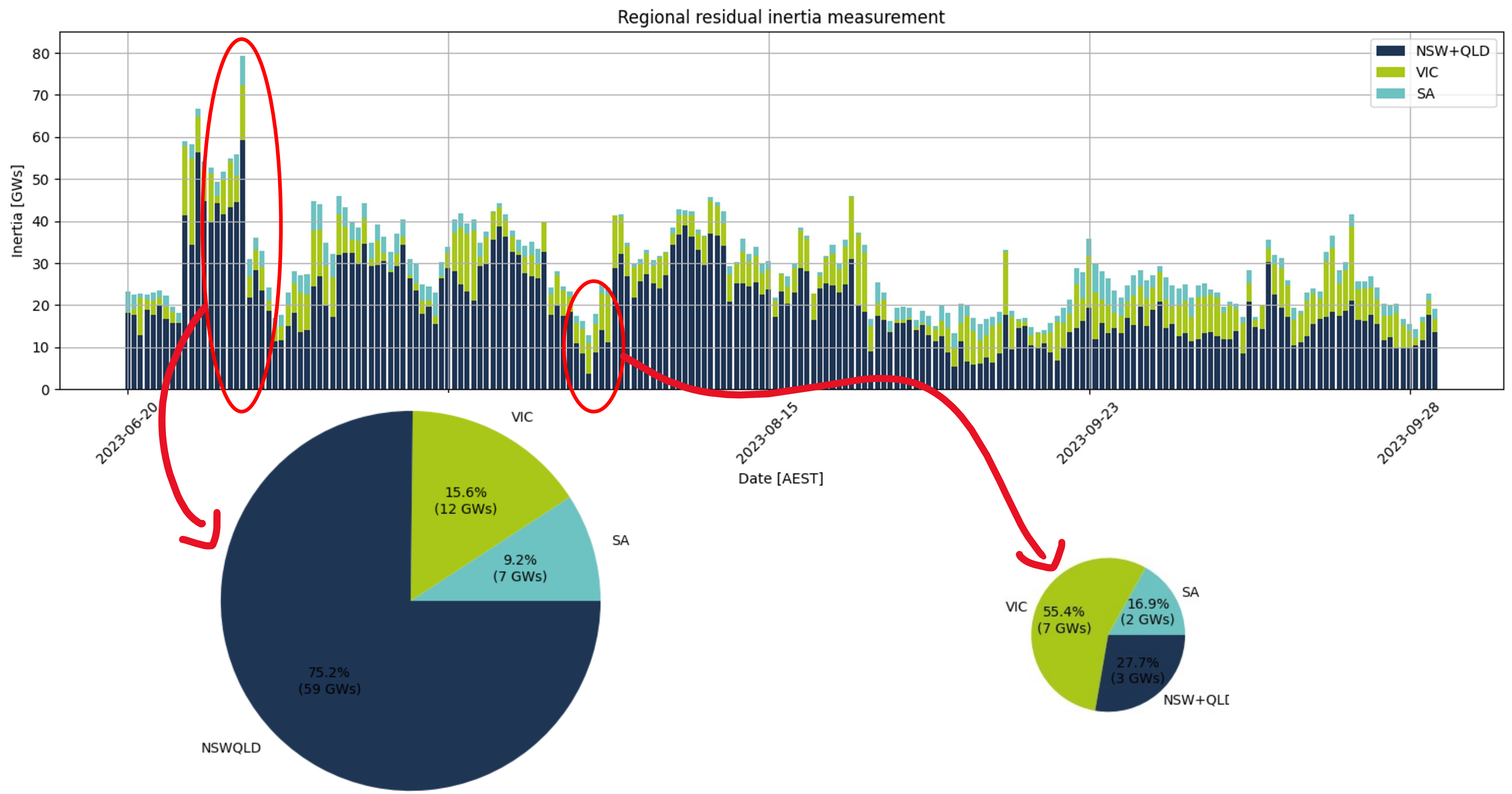
On average 32 GWs of inertia is "hidden"



5th percentile 15%

5th percentile 13 GWs

Regional Inertia in the Australian NEM.



Thank you!

Questions?

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