NASPI Work Group Meeting, 13th April 2021

Effective Area Inertia:

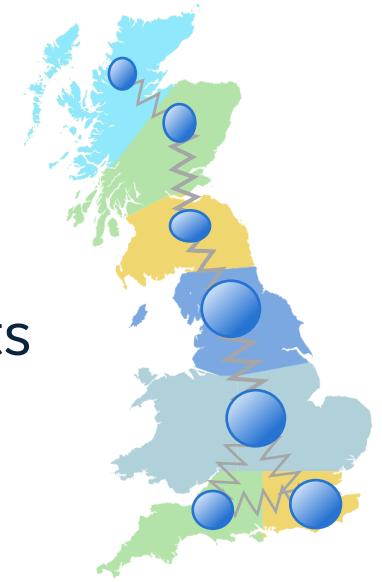
Stability **Challenges**

PMU-Based **Metering**

& Machine Learning **Forecasting**

Background: Inertia & Challenges

Power System Disturbances: **Centres of Inertia**

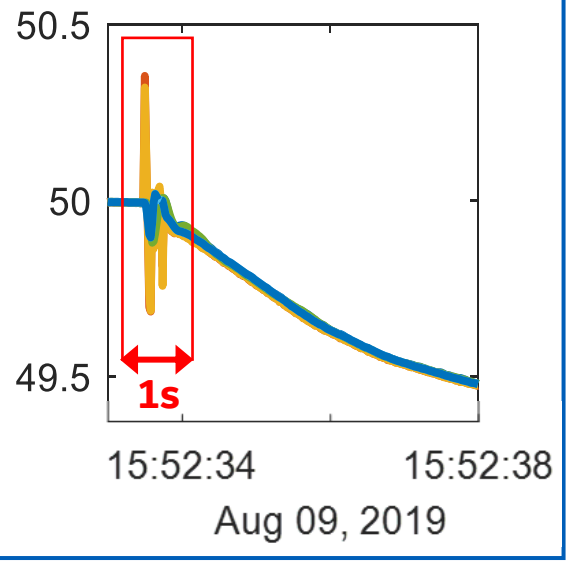


A power system behaves as area **centres of inertia** (“masses”)
linked by the network (“springs”)

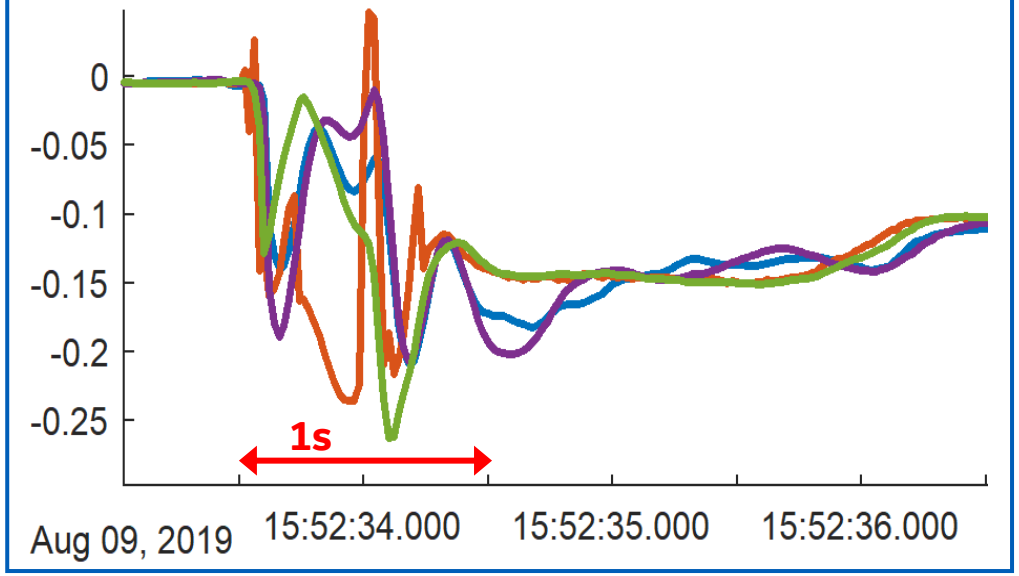
Significant spread of **Frequency & RoCoF** across a grid during events

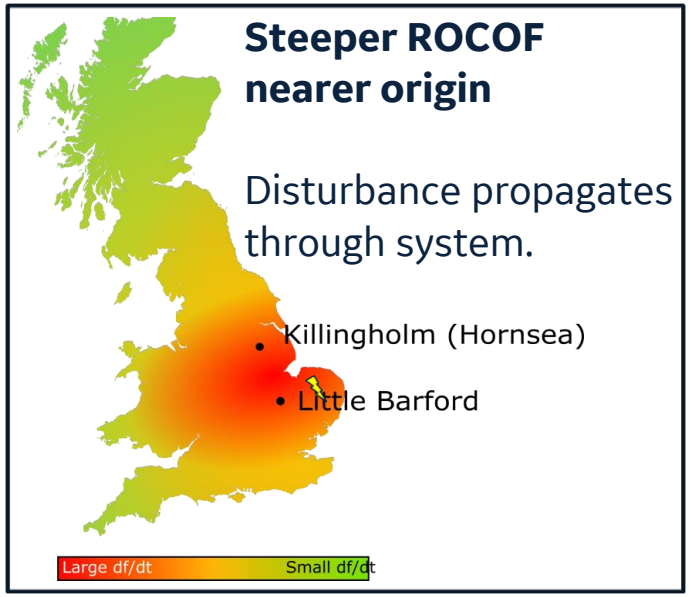
Example: Great Britain 9th August 2019

Frequency



Local Rate of Change of Frequency





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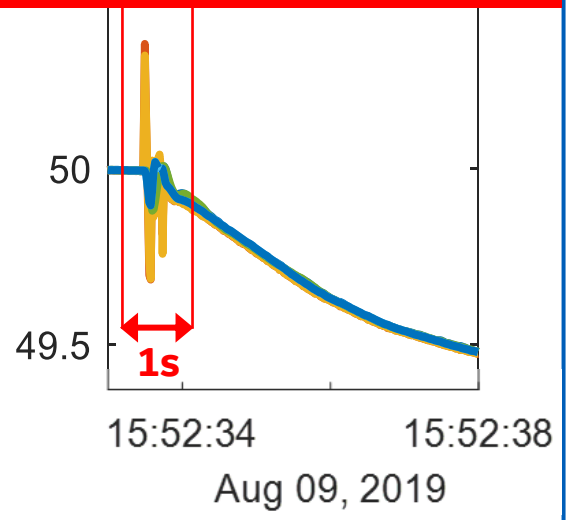
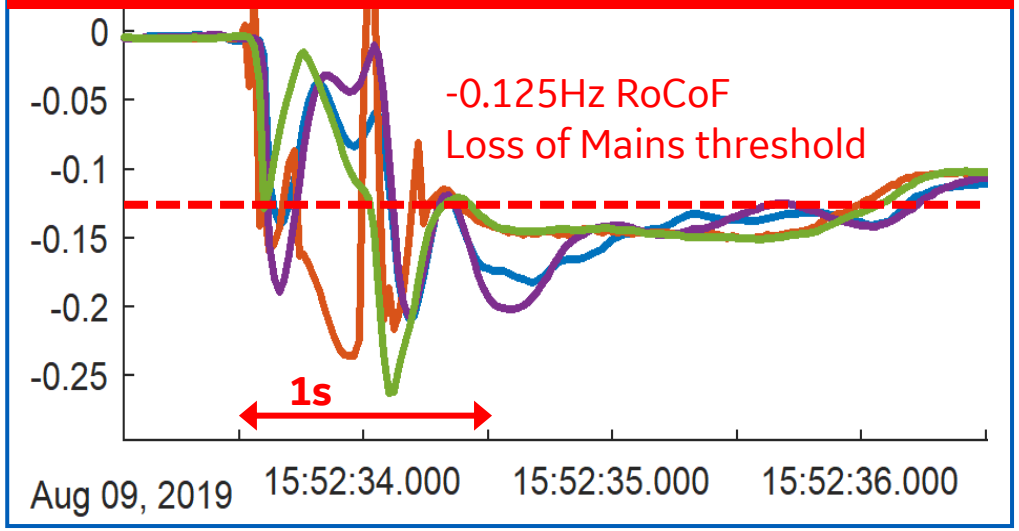
Frequency

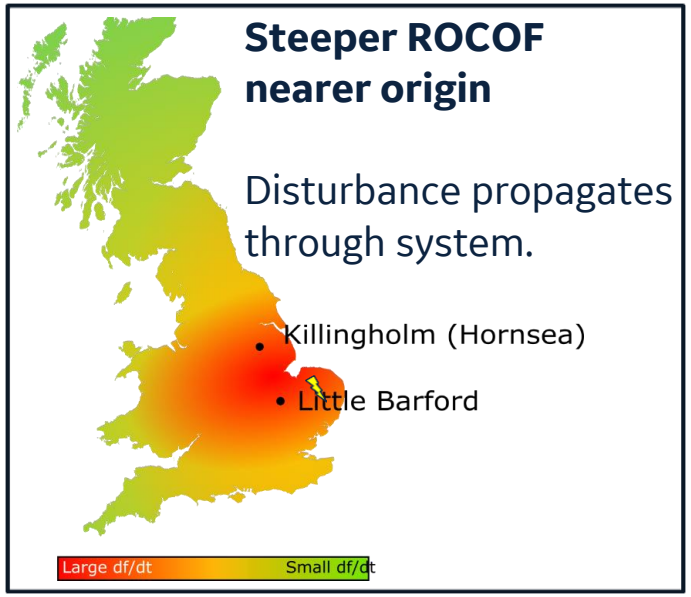
Risk: Centres of Inertia Separate



Local Rate of Change of Frequency

Risk: Embedded Generation disconnects - Loss of Mains



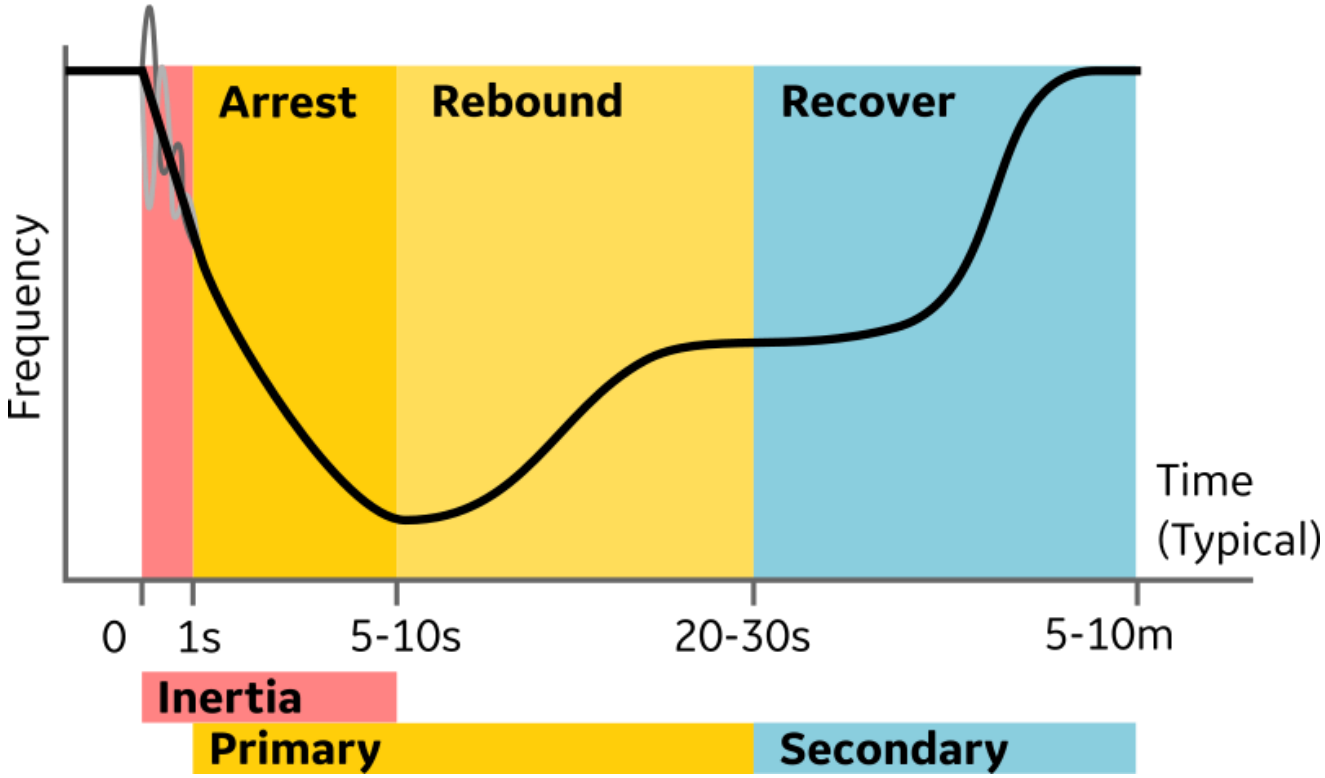


Effective Inertia

Relates **power imbalance** in a grid to the
rate of change of frequency that immediately results

Ability of a grid to
resist changing speed *due to a*
generation/demand ***imbalance***
or a ***fault***

“Grid” can be whole interconnection
or a coherent region
– a **centre of inertia**



Effective Inertia: **Why It Matters**

Low Inertia means in a disturbance:

- **Frequency falls faster & further**
  before primary response kicks in
- **Risk of Loss of Mains Disconnection**
  Embedded Generation disconnects at high RoCoF
- **Stability / Separation Risk**
  Area **angles move faster**
  Fast response in **wrong place** can **destabilize**

Resulting in **Additional Costs:**

- **Enhance Primary Response**
  larger volume and/or **faster delivery** needed
- **Procure Inertia**
  Generation trading or **dedicated 0 MW plant**
- **Tighten Constraints**
  Largest single potential loss of generation
  Inter-region flows for transient stability

Effective Inertia: **Sources**

Physical Rotating Inertia at Transmission
Steam/Hydro/Gas turbines
Synchronous Condensers

Load
Rotating machines
Other passive/active behaviour

Inverter-Based Resources
Solar/Wind Generation
HVDC Links
Energy Storage

Well Known

"Residual"
Less Known

Then / Now
High inertia
Neglect Residual

Now / Future
Low inertia
Residual significant

Measurement & Forecasting of Effective Inertia is becoming **critical** to grid operation

Inertia Metering Using PMUs

Area Effective Inertia Metering Using PMUs

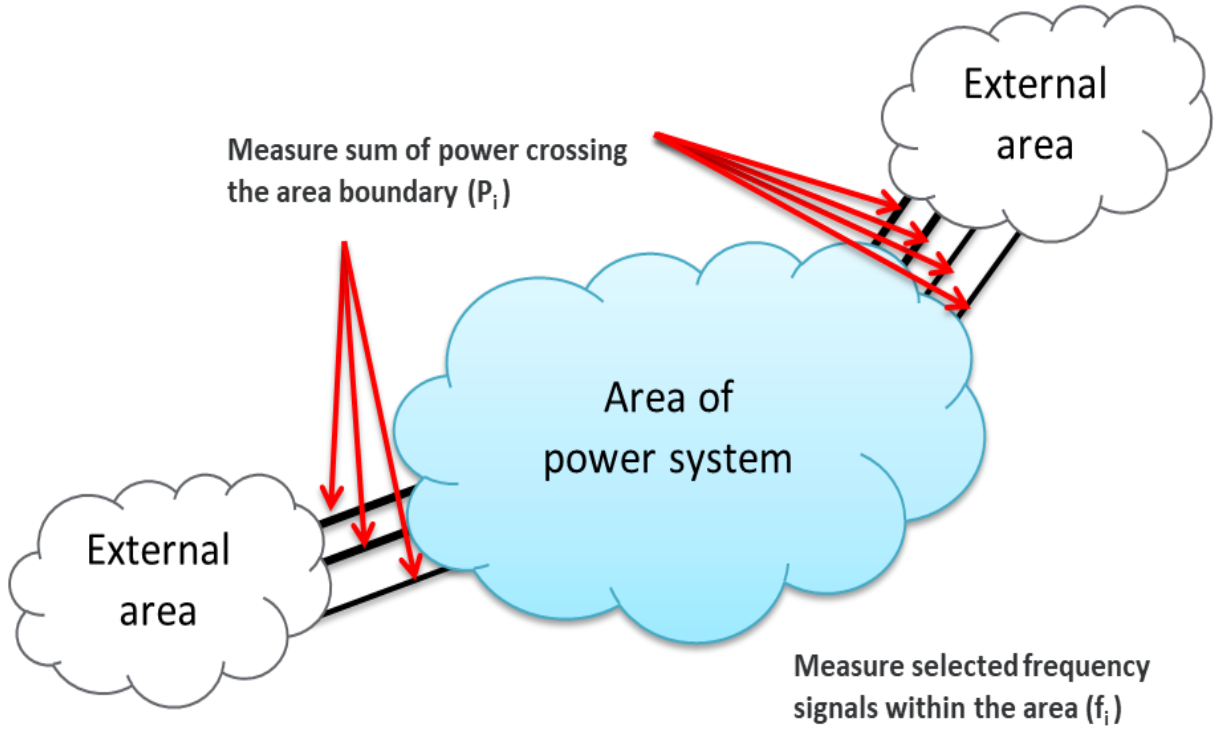
Continuous, passive metering of **Area Effective Inertia** using standard **PMU** measurements.

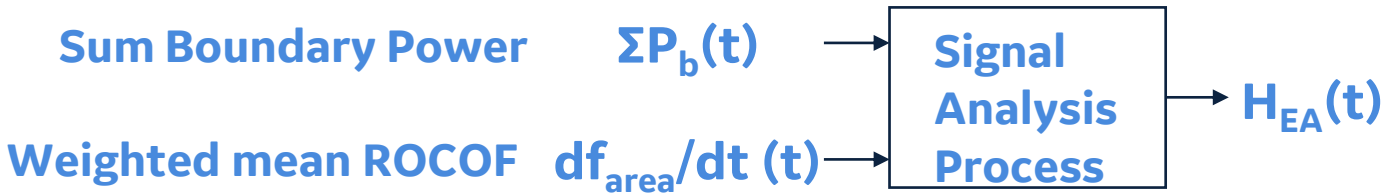
No deliberate excitation of system.

Only modest PMU measurements required:

- **Area boundary power:**
  V & I for transmission lines forming boundary

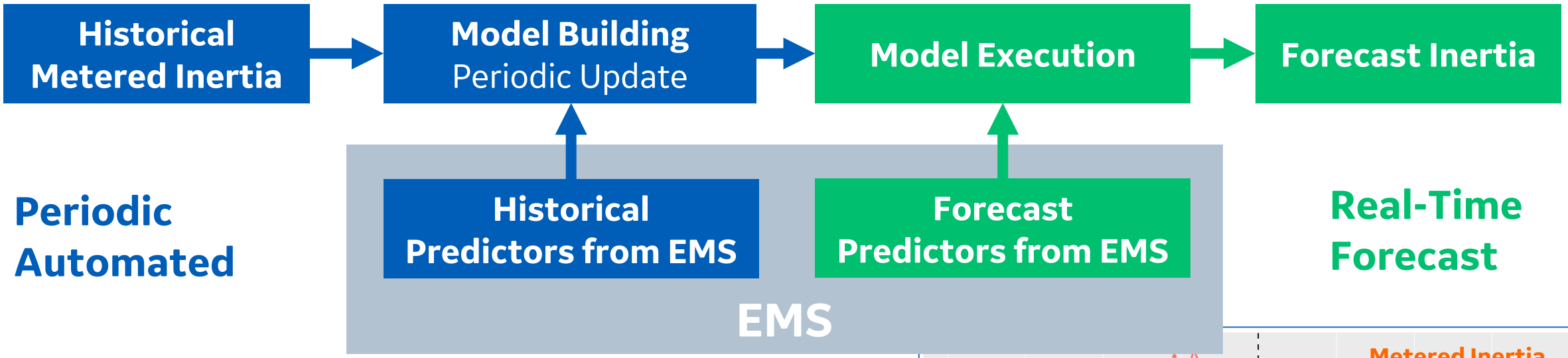
- **Area frequency:**
  Few key measurements within area (e.g. 3-4)
  To give representative area frequency





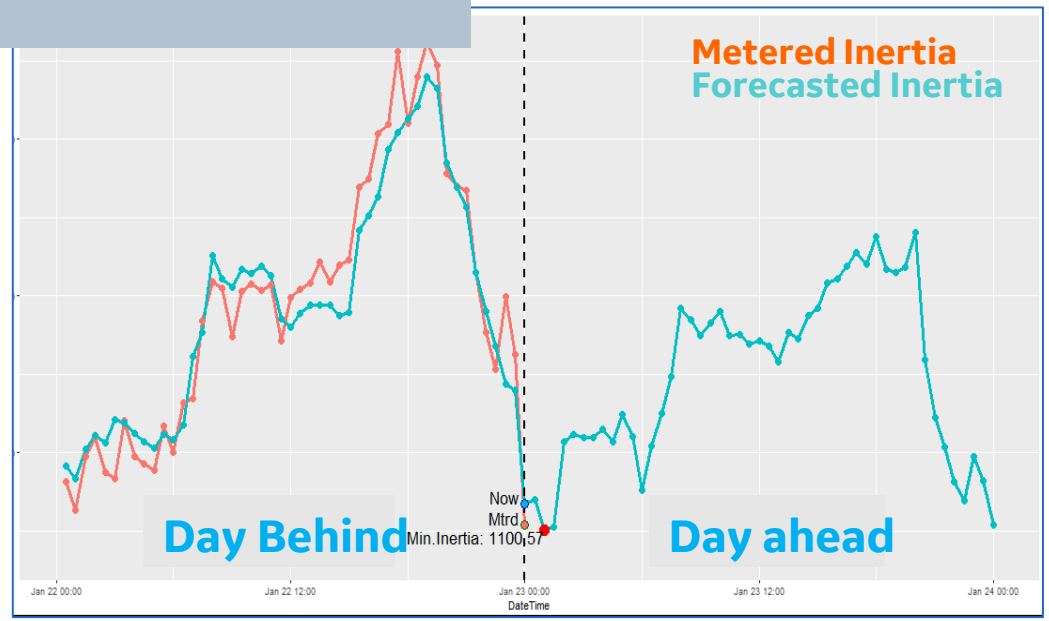
Inertia Forecasting

Area Effective Inertia Forecasting



Machine Learning model links **inertia** to **predictor variables**, on a **per-area** basis:
E.g. *Demand, Synchronous Inertia, Wind, Solar*

Confidence intervals calculated,
Validated against metered and event inertia



Offline Field Testing: SP Energy Networks

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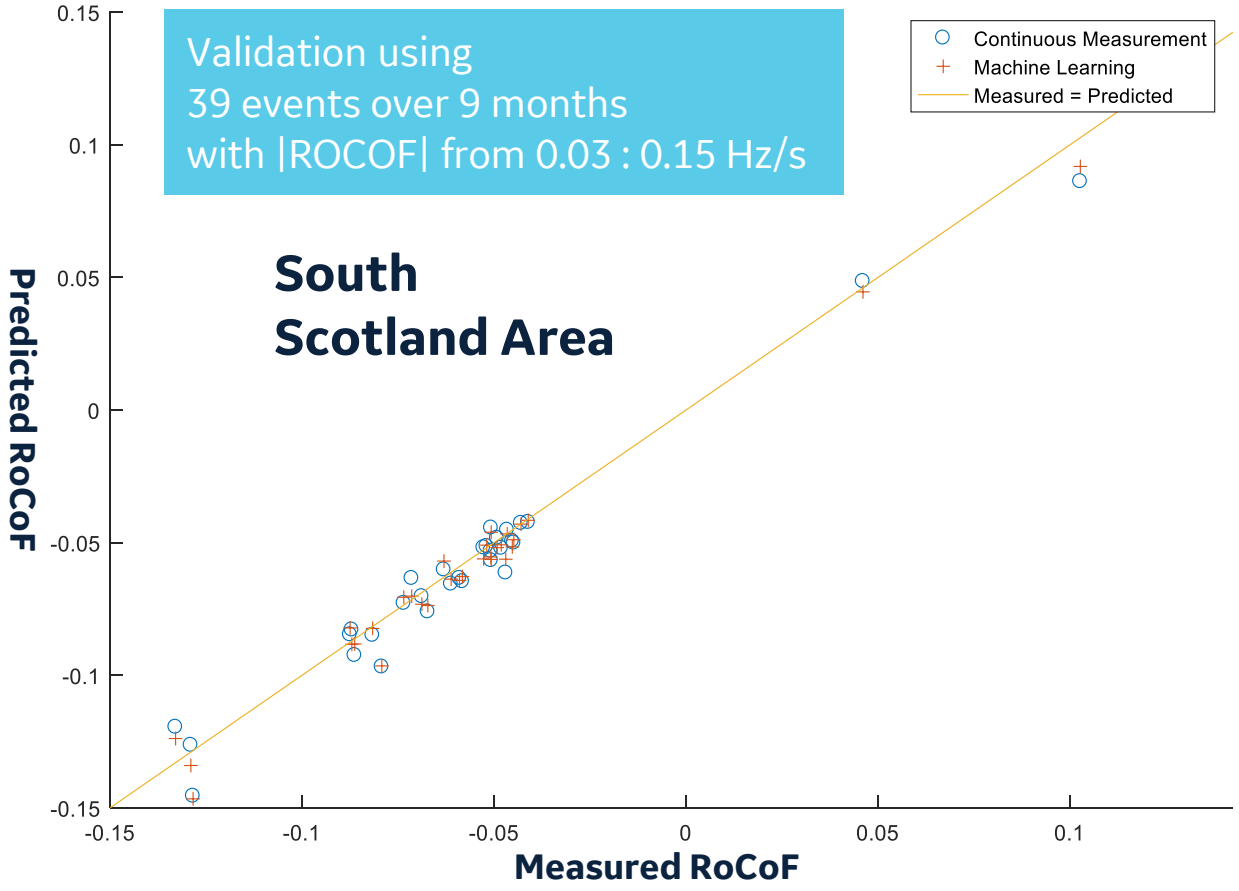
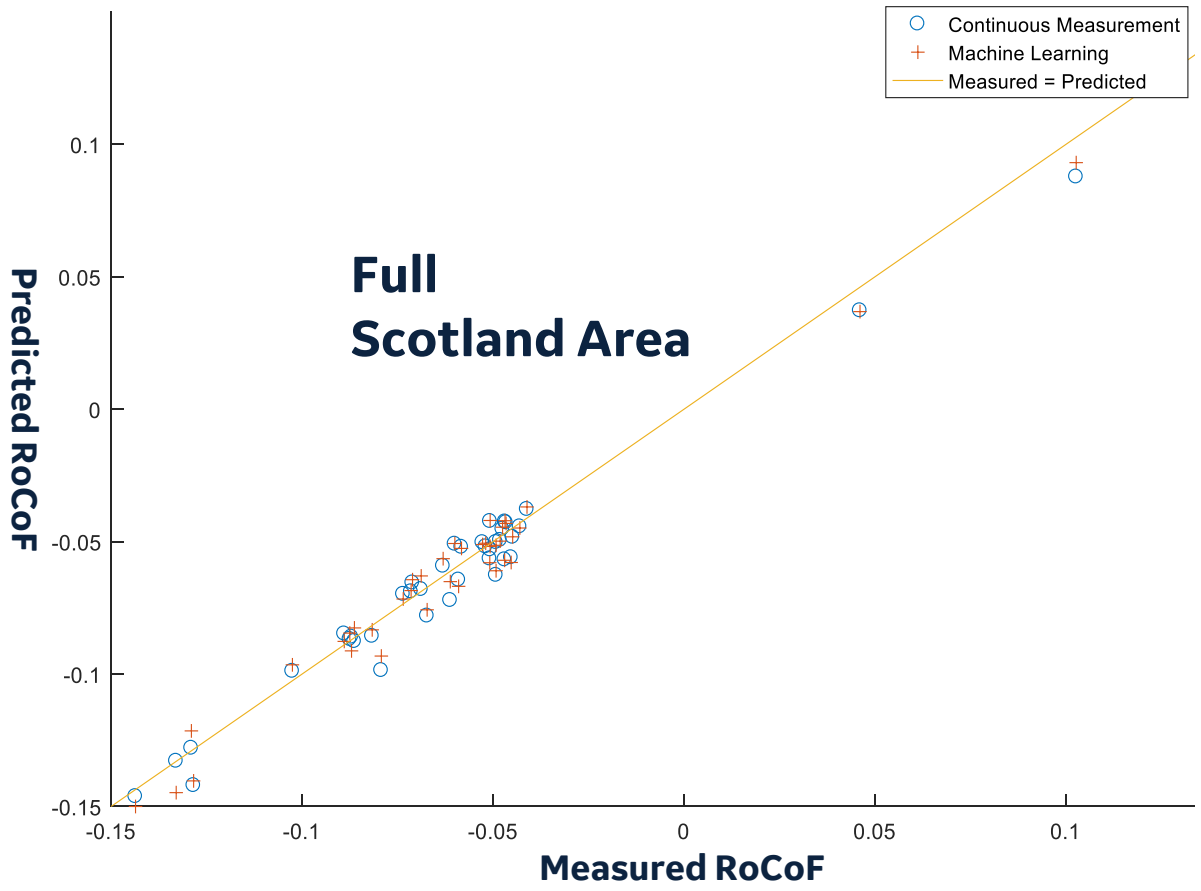
Inertia Metering & Forecast values for South Scotland and Full Scotland Areas

Validated against real system RoCoF behaviour during events

Validation using
39 events over 9 months
with |ROCOF| from 0.03 : 0.15 Hz/s





Operational Deployment: National Grid ESO, GB

National Grid ESO, GB: Operational Deployment

Inertia Metering online

- Continuous, live visibility of Scotland inertia ongoing for >40 days
- PMU connections under way to cover remaining regions of GB

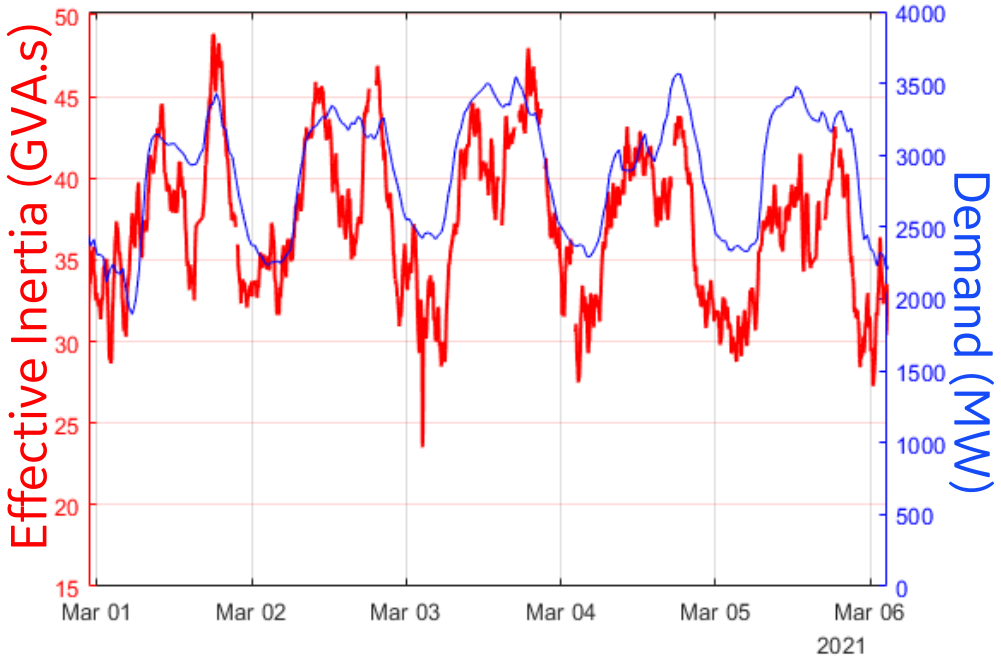
Inertia Forecasting imminent

- Model training underway
- Pending go-live of feed from operational systems

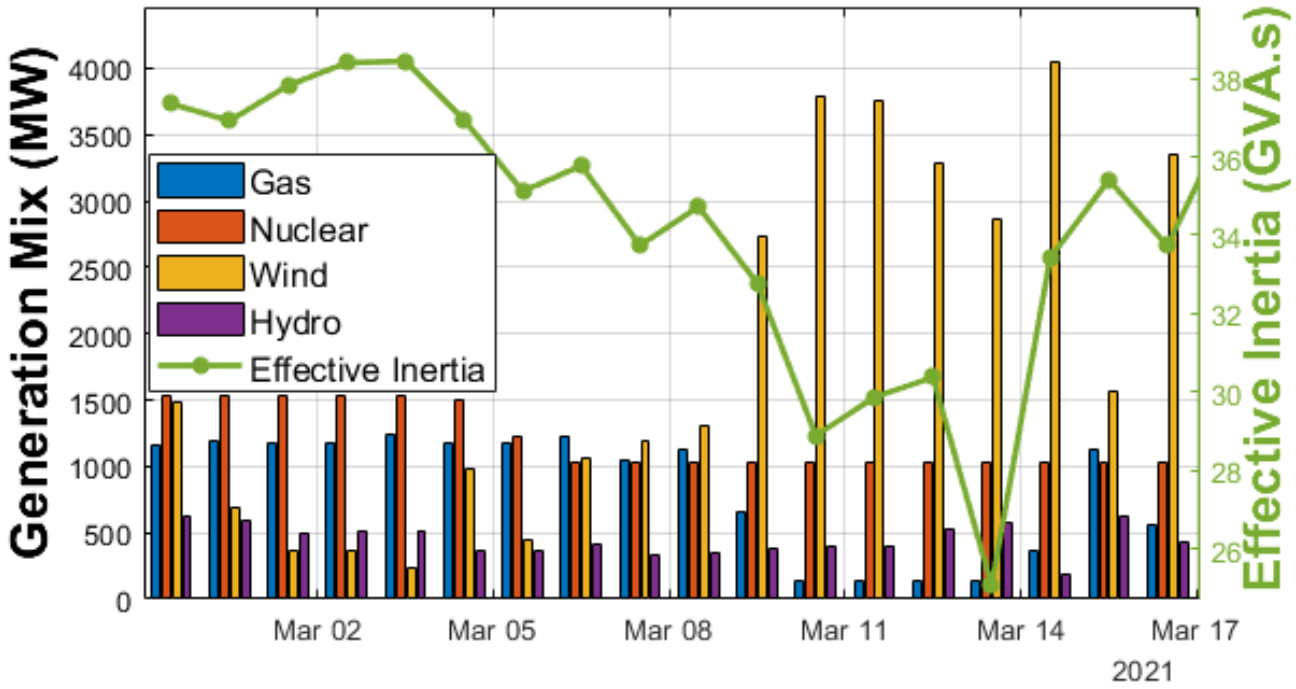
National Grid ESO, GB: Operational Experience

Results match expectations: consistent with variations in demand & energy mix

Example:
Correlation with Demand



Example:
Correlation with Low Synchronous, High Wind



Regular automated validation against real system behaviour during events.

Conclusions

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1. **Inertia** is a **regionally distributed** parameter affecting **local RoCoF** and **stability**,
   not just system frequency

2. **Effective Inertia** covers all contributors to the **P-RoCoF relationship**,
   not just physical rotating transmission generation.

3. **PMU-based metering** of Effective Area Inertia is **passive**, uses standard PMU measurements, and is **in operation now**.
   Informs secure system operation, planning & analysis.
   Can feed **wide-area control** driven fast frequency response for islanding avoidance / ride-through.

4. **Machine Learning** yields **forecast of inertia** – field-deployed offline, **operational go-live soon.**
   Insight into system sensitivities, and real-time validation of inertia metering.