cigre PARIS 2022

nationalgridESO

Study Committee C2

Power System Operation and Control

10198_2022

Operational metering, forecast & validation of effective Area Inertia

Stuart W A CLARK[1]*, Douglas H WILSON[1], Karine HAY[1], Anna BLACKWELL[2]

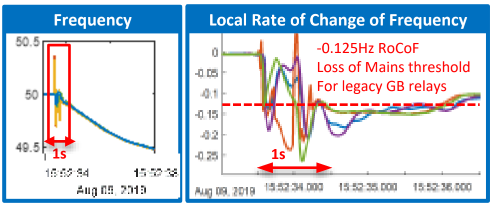
GE[1], National Grid ESO[2]

What Inertia Is

- Relates **power imbalance** in a grid region to the **rate of change of frequency** (RoCoF) that immediately results

$$Effective\ inertia = \frac{-\Delta P\, f_0}{2\, RoCoF}$$

- A power system behaves as **area centres of inertia** ("masses") **linked by the network** ("springs")
- In a disturbance, we see **significant spread** of **frequency** and **RoCoF** between the centres of inertia in a power system



Example: Great Britain (GB) 9th August 2019

Why Inertia Matters

Low Inertia means in a disturbance:

- **Frequency falls faster & further**
  in first seconds before primary response kicks in
- **Stability / Separation Risk**
  Area angles move faster
  Fast response in wrong place can destabilize
- **Risk of Loss of Mains Disconnection**
  Embedded Generation disconnects at high RoCoF – exacerbating power imbalance and inter-region stress

Contributors to Inertia

Bulk Synchronous Plant
Steam/Hydro/Gas generation
Flywheels

"Rotating Inertia"
Easy to know

Load
Rotating machines
Other passive/active behaviour

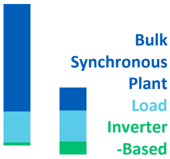
Inverter-Based Resources
Solar/Wind Generation
HVDC Links
Energy Storage

Effective Inertia
Includes "hidden" contributors

Trends in System & Regional Inertia

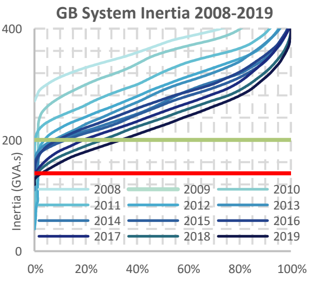
- **System inertia reducing:** overall and minimum values
- **Large inertia sources becoming sparse**, especially in scenarios with high renewables
- **Regional distribution** of inertia **becoming key** to frequency control and grid stability
- Known bulk synchronous plant contributes a smaller proportion of overall **inertia – larger proportion from "hidden" sources**

Example: GB System
Since 2008, overall inertia reduced by >30%,
5% percentile reduced by 50%



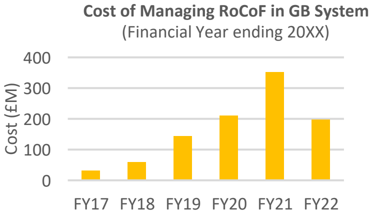
Then / Now
High inertia
Easy to estimate

Now / Future
Low inertia
Harder to estimate



Costs of Managing Lower System / Regional Inertia

- **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



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

http://www.cigre.org

Study Committee C2

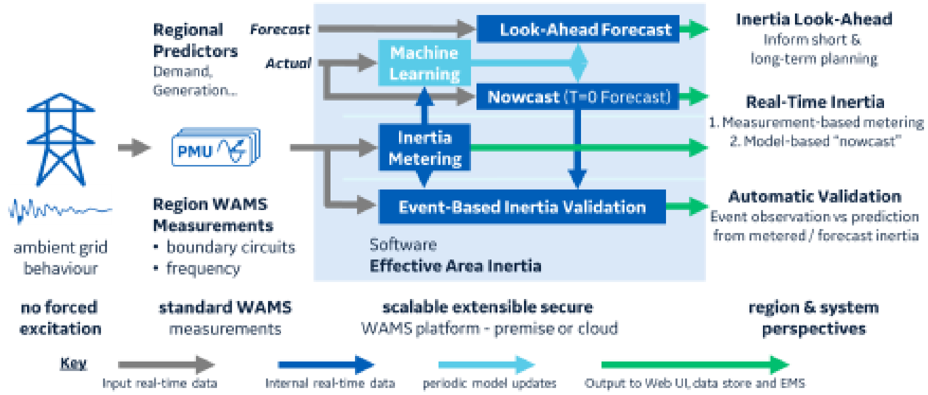
Power System Operation and Control

10198_2022

Operational metering, forecast & validation of effective Area Inertia

continued

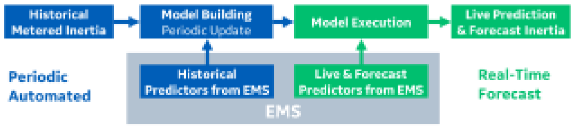
Solution: Effective Area Inertia Metering, Forecast & Validation



Inertia Metering

- **Measurement-based:** no deliberate excitation, power system model information or machine learning is used
- **Inputs:** standard PMU data for each region:
  - **Power flow** on region boundary lines
  - **Frequency** within region (2-5 sites to give representative regional value)
- **Output:** region inertia, with confidence band
- Present deployment operates with a **30-minute window** of **10fps data**, **updated every 5 minutes** - all configurable.

Inertia Forecast



- **Machine learning** model links **inertia** to **predictor variables**, on a **per-region** basis: *e.g. Demand, Synchronous Inertia, Wind, Solar*
- **Model executed in real-time** on:
  - **Live predictor** values to give model-based "**nowcast**" prediction of live inertia – backup & cross-check for PMU-metered inertia
  - **Forecast predictor** values to give **look-ahead inertia forecast** Presently running on 24h-ahead, 30min interval forecasts – updated every 5min.
- **Model automatically updates** periodically to learn from the most recent metered inertia and predictor data

Inertia Validation

- **Validates** measurement-based **metered** and model-based **nowcast inertia** against **real system disturbances**
- Gauges inertia accuracy by **comparing:**
  - **Predicted RoCoF** based on **inertia** and disturbance in region **power imbalance**
  - **Observed RoCoF** from PMU measurements
- **Fully automated:** disturbances detected, analysed, and results stored

Solution deployed at the GB Electricity System Operator since late 2021,
operating on the Scotland region of GB
– full GB visibility pending key PMU installations

http://www.cigre.org

Study Committee C2

Power System Operation and Control

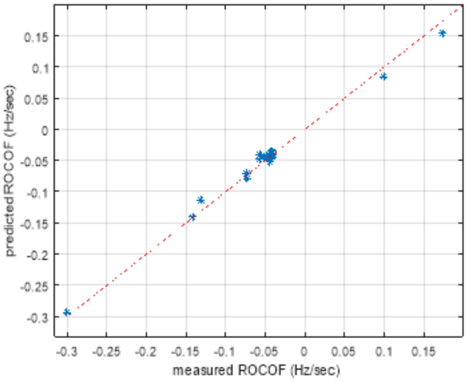
10198_2022

Operational metering, forecast & validation of effective Area Inertia

continued

The Solution in Operation

Results to Date: Inertia Metering



Validation of metered inertia for the Scotland region: comparison of observed RoCoF against RoCoF predicted by metered inertia and disturbed regional power import/export.

19 suitable disturbances over a 7-month period

- **80%** (15 events) : **≤10% or 10 mHz/s error** in predicted RoCoF
- **96%** (18 events) : **≤15% or 15mHz/s error** in predicted RoCoF
- **100%** (19 events) : **≤20% or 20mHz/s error** in predicted RoCoF

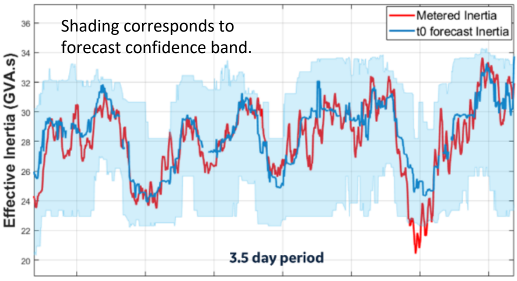
20mHz/s is equivalent to 2% of the 1Hz/s Loss of Mains protection threshold defined in the latest GB ENA G99 / G59.3-7 regulations.

Results to Date: Inertia Forecast

Example comparison of measurement-based inertia metering against machine-learning model-based inertia “nowcast” driven by live generation & demand values.

Notable factors that could contribute to differences between metered and forecast:

- Variation in load makeup
- Behaviour of unmonitored embedded generation



Next Steps

- Further performance review over a longer period
- Progress GB PMU rollout at key locations and circuits, to complete GB regional inertia visibility and enable metering and forecast of GB whole-system inertia