GE VERNOVA

ADDRESSING PRACTICAL STABILITY CHALLENGE OF A TRANSFORMING GRID

Methods and Infrastructure for addressing risks of unstable oscillations

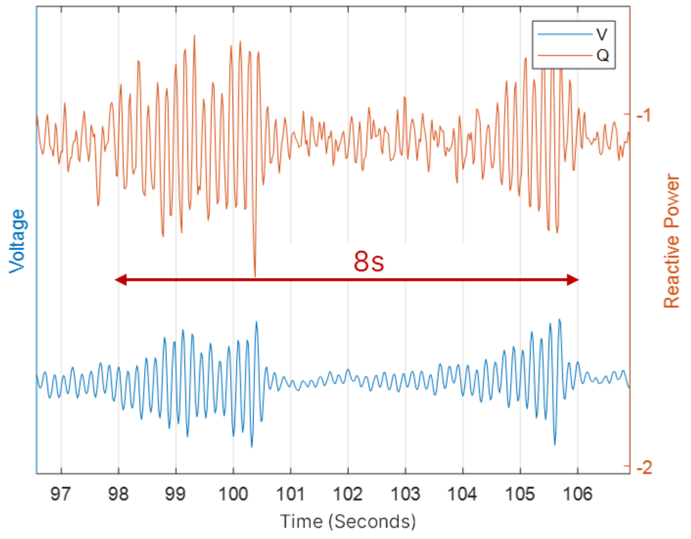
Douglas Wilson

11 Feb 2026

The Oscillation Problem

GE VERNOVA

Example of 6Hz oscillatory instability due to IBR control

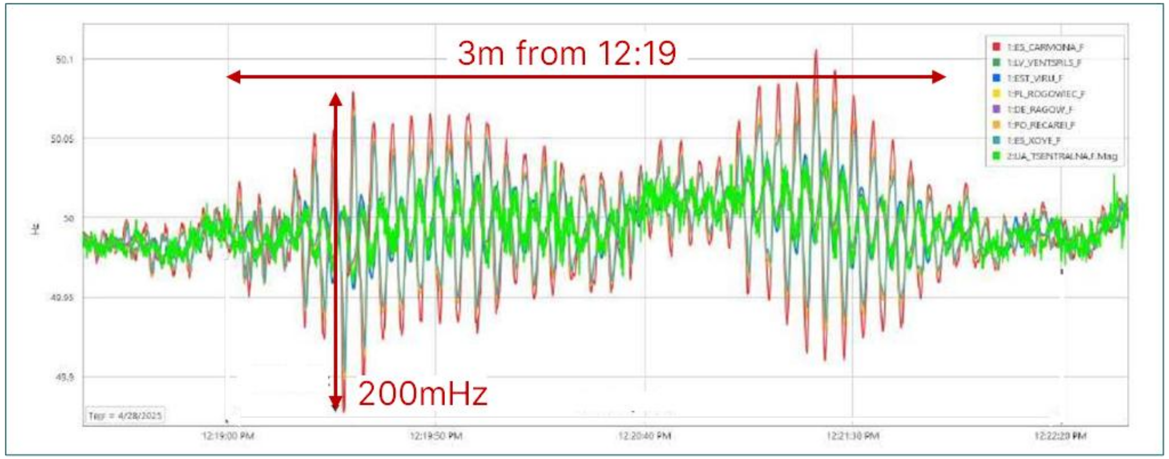


Impacts of Oscillations

- Grid instability and cascading failures
- Control System interactions
- Reduced Power Transfer
- Power Curtailment
- Power quality and flicker
- Equipment Stress and Damage
- Grid Connection Delays

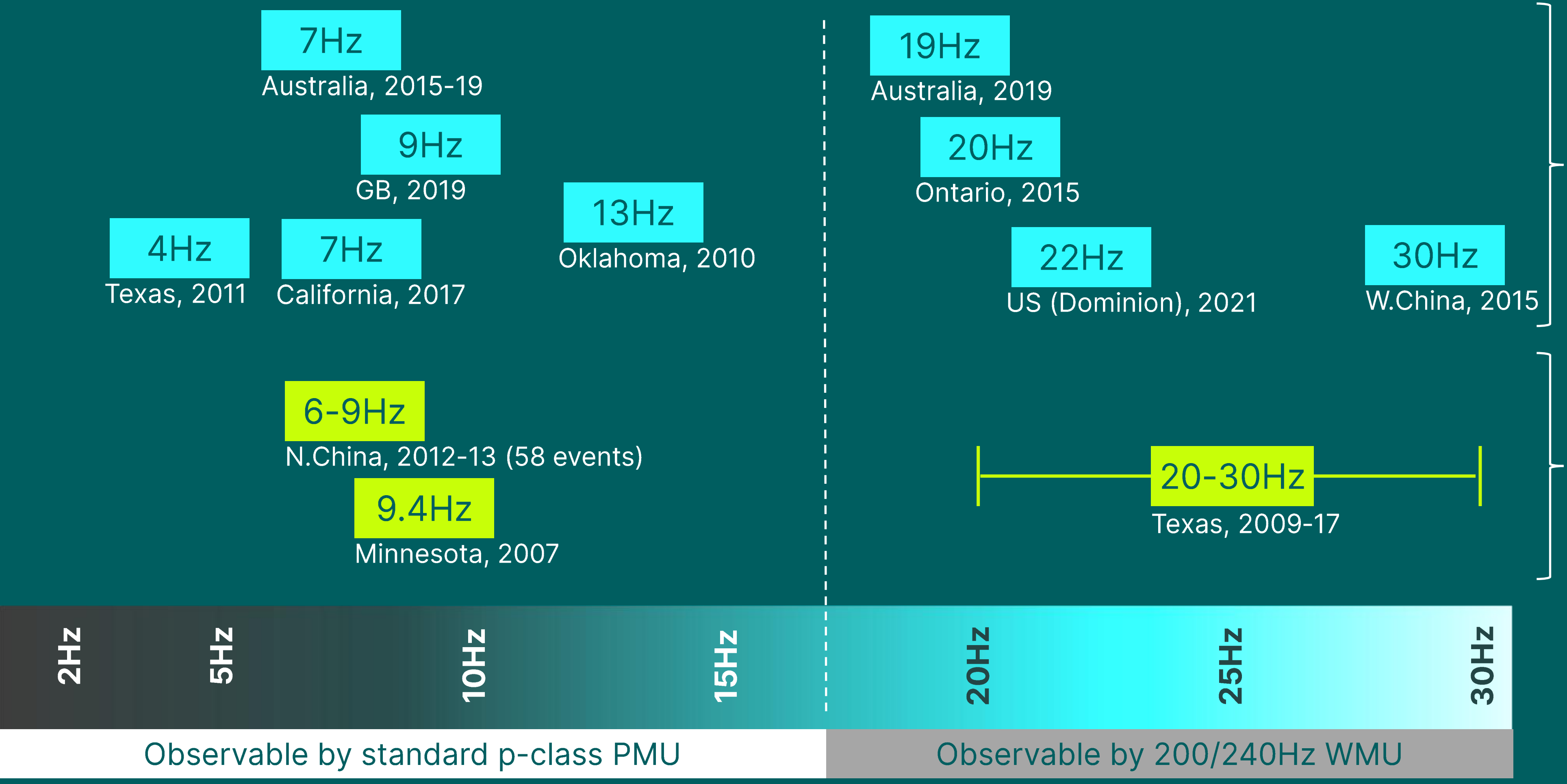
Example of 0.2Hz instability in Iberia outage 28 Apr 2025

(10 minutes before collapse)



IBR Oscillations: Real-world experience

Source: Cheng Y et al, “Real-world Subsynchronous Oscillation Events in Power Grids with High Penetrations of Inverter Based Resources”, IEEE Trans Power Systems Vol 38 No 1 Jan 2023



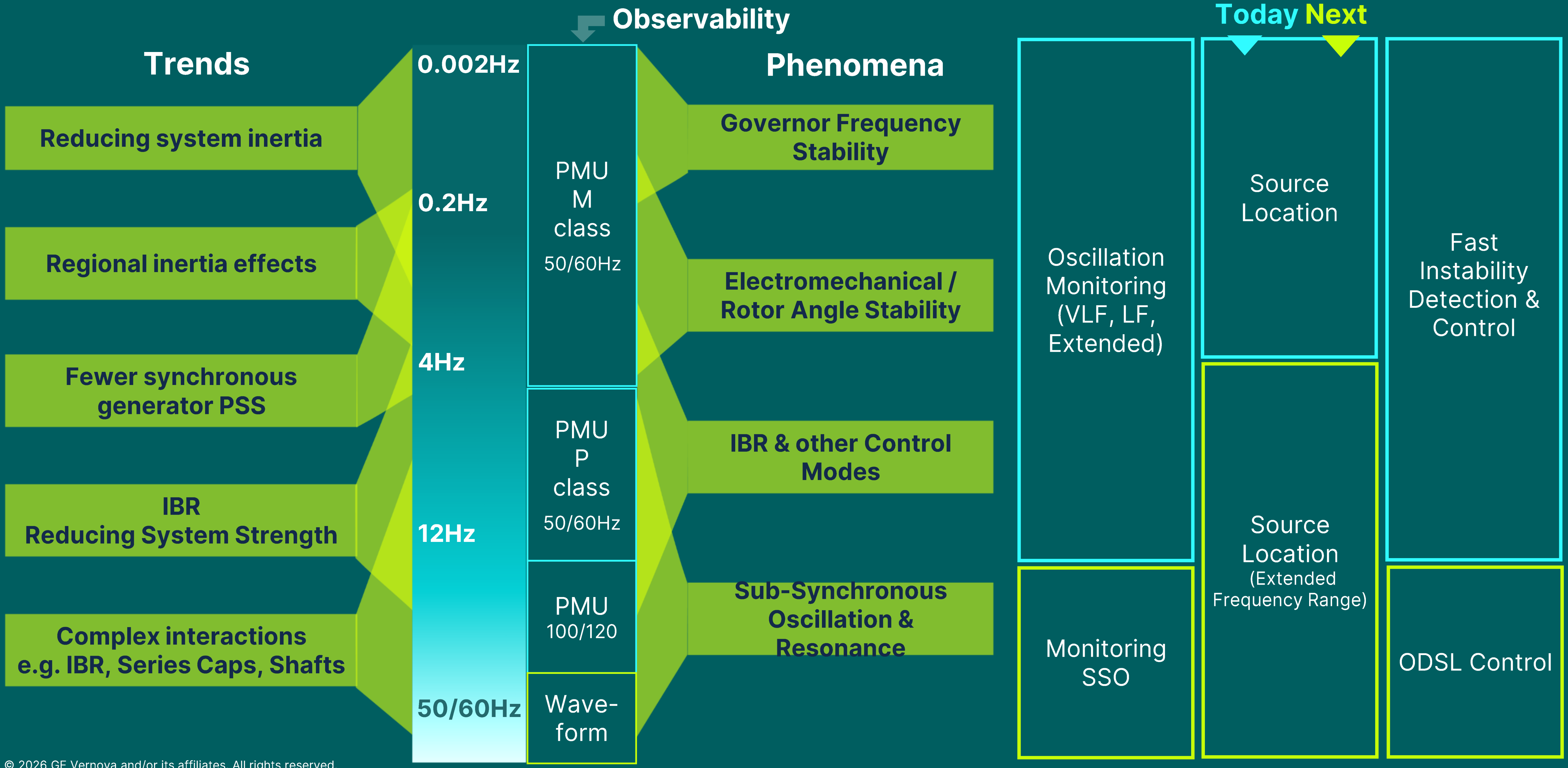
Weak Grid oscillations

- IBR Power level high and/or weak system strength
- Unsuitable PLL parameters
- Voltage control too fast / high gain
- System strength weakening by network or generator trips

Series Capacitor interaction

- Series compensated network
- Change of topology affective compensation level
- Interaction of LC mode with IBR control mode

Oscillation Issues, Frequency Ranges and Solutions



From the Grid Perspective

GE VERNOVA

Detect oscillations
- Damping issues
- Large / growing

Classify oscillation by
- Observability – signal types (|V| ,Vδ, |I| ,Iδ, F)
- Geographic
- Modulation, addition
- Core phenomena

Locate sources
- Distinguish source vs sink
- Plant or Zone level

Data recording
- System state (dynamic - WAMS)
- All relevant waveforms

Real-time fix: short-term
- *Guided operator response*
  - Ramp down
  - “Weak mode” control
  - Shutdown / trip

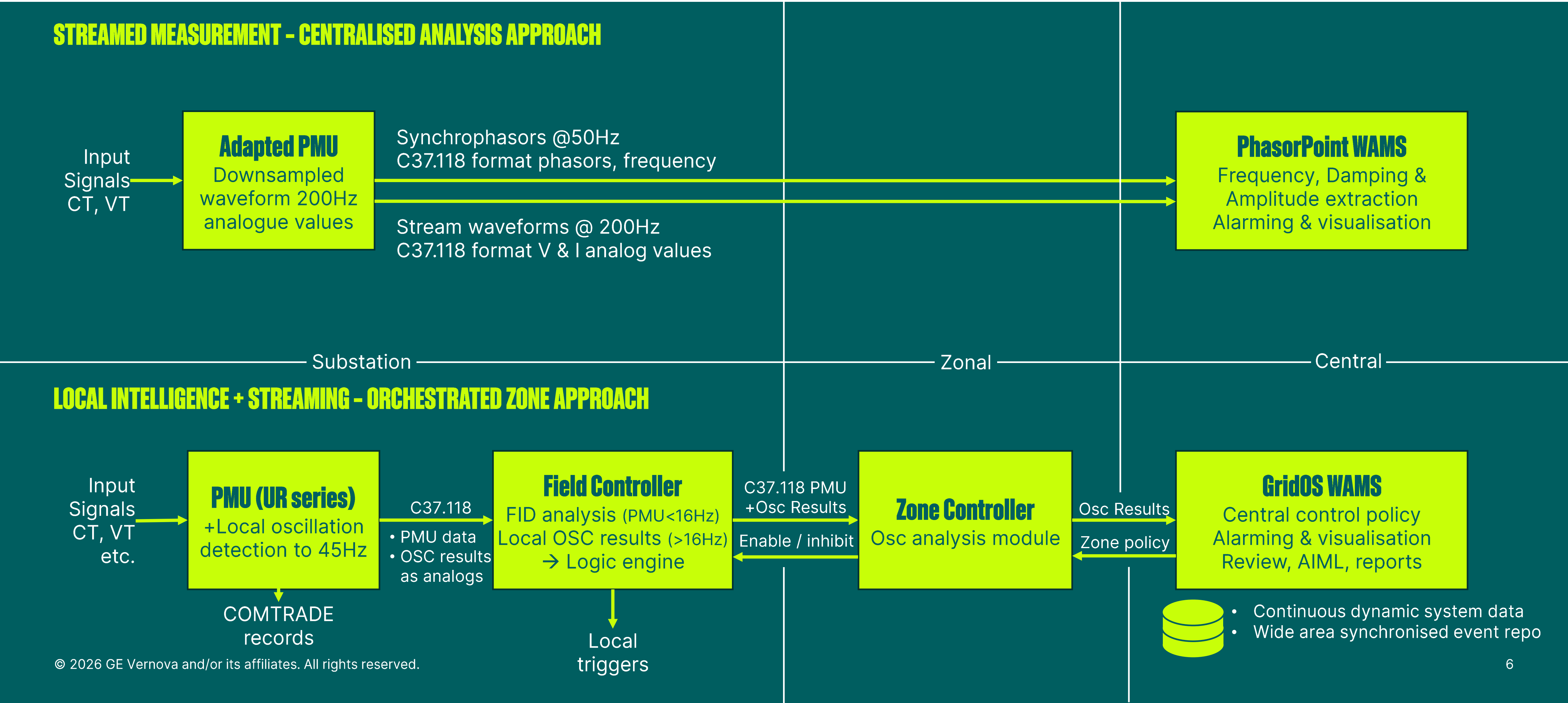
Automated Real-time
- *Automatic select & trigger*
  - Ramp down
  - “Weak mode” control
  - Shutdown / trip

Control Tuning
- Model revision
- Problem replication
- Control tuning & test

Commission & Probation
- Monitor commissioning tests
- Trial period + report

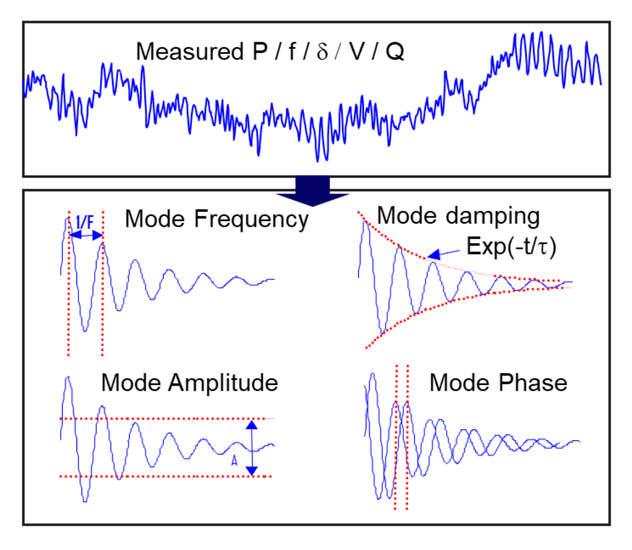
Data for Higher Frequency Oscillation Analysis

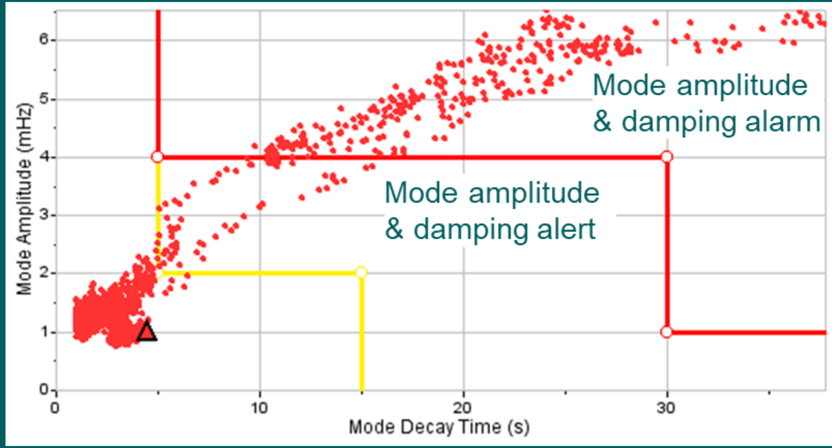
GE VERNOVA

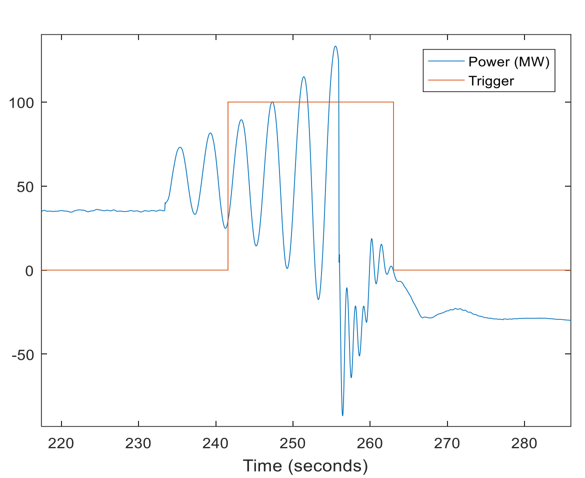


From Measurement to Control

GE VERNOVA







Planning, Analysis, Performance

- Post-event analysis
- Dynamic performance baselining
- Dynamic model validation
- Damping controller performance assessment

Real-time Operations

- Early warning of poor damping
- Frequency banding
- Alarms on **mode damping** and **mode amplitude** per band
- Source location methods

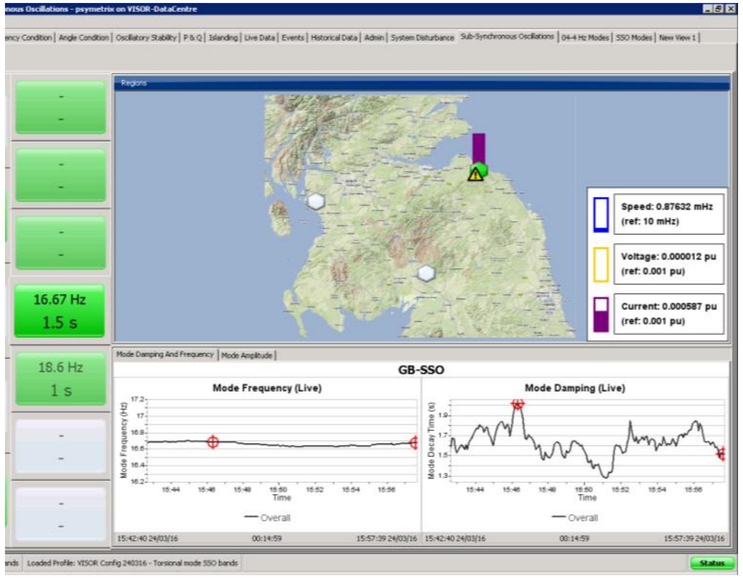
Real-time Control

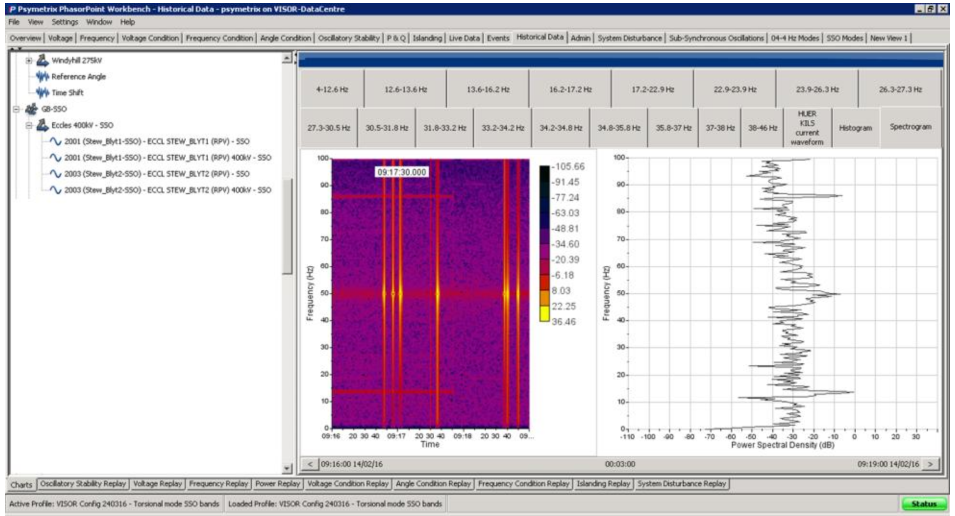
- Fast identification of instability
- Wide-area processing to target the locations
- Zonally enabled actions
- **Fast response** to critical instabilities

Long Term → **Real-Time**

Sub-Synchronous Interactions

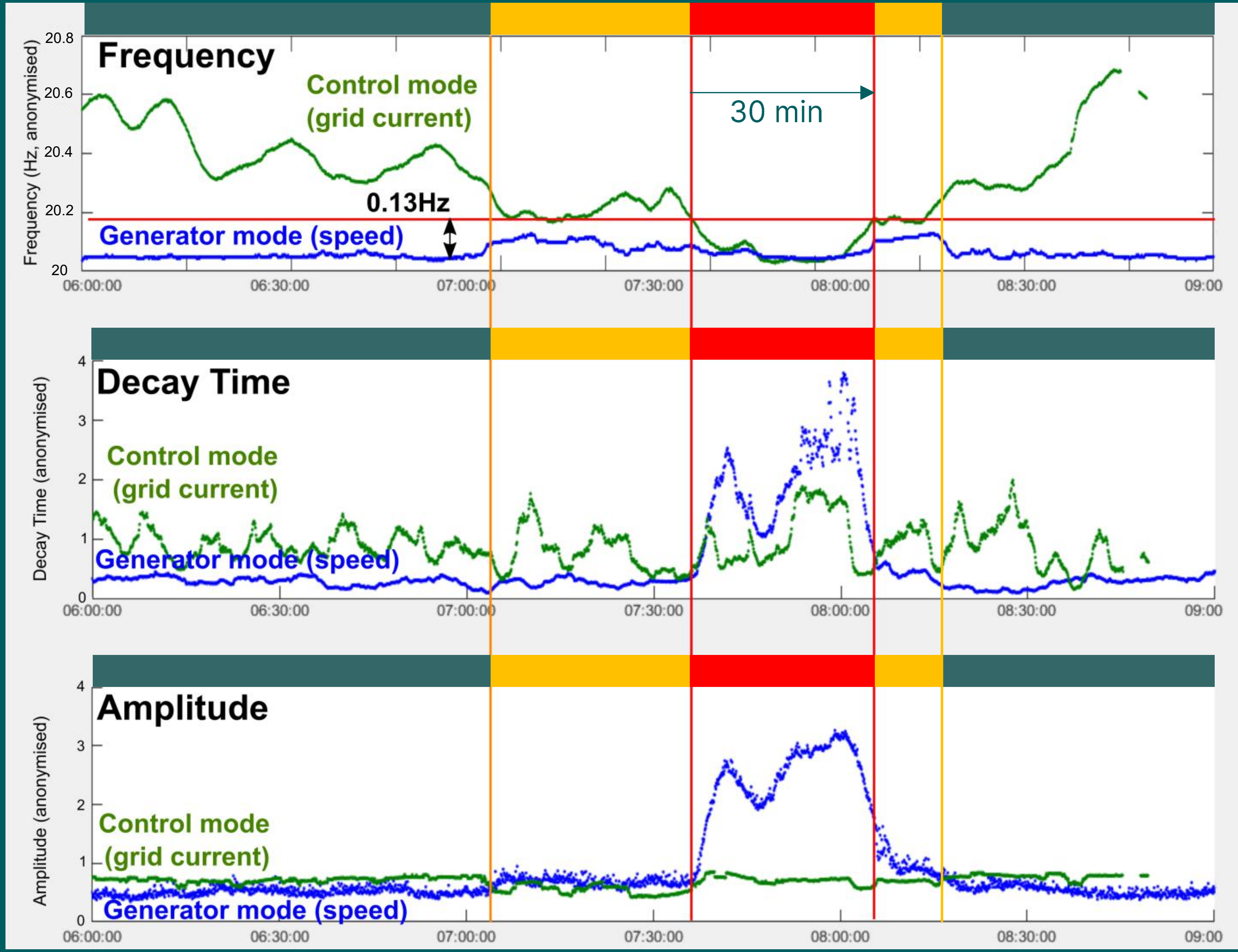
- Oscillations above 20Hz not observed by PMUs
  PMU bandwidth inherently limited by phasor window
- Sub-synchronous Interactions can occur at 16-60Hz
- Filter & downsample waveform to 200Hz, retaining bandwidth up to ~80Hz
- Central processing & oscillation analysis for real-time & historic data





Example of Torsional Mode Interaction

GE VERNOVA



Known torsional mode
- Visible in waveforms

Control mode
- Seen over a wide area
- Sporadic occurrence
- Mobile frequency

Signs of interaction
Raised amplitude when control mode close to torsional mode

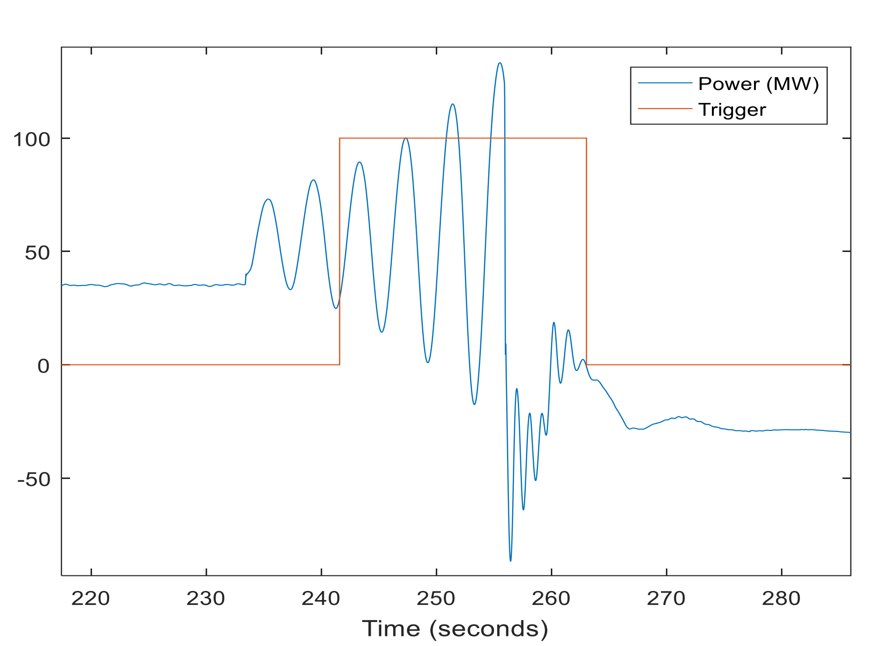
Monitoring based investigation
- Location from mode shape
- Timings of occurrence

Sources identified
End user equipment malfunction
Monitored for recurrence

Phasor-Based Fast Instability Detector

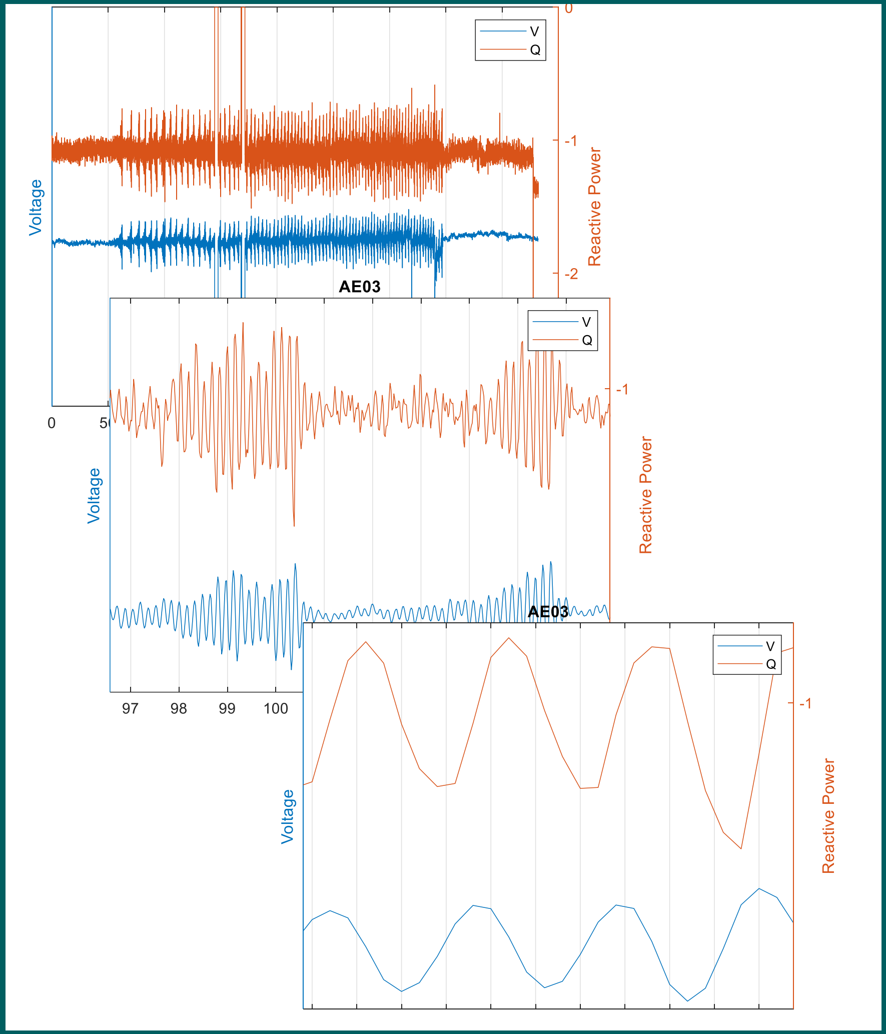
GE VERNOVA

- PhasorController Application Function Blocks (AFBs)
  - Fast Instability Detector
  - Thresholder – amplitude & damping criteria
- Detect raised amplitude and poor damping
  - Trigger time < 3 cycles
- Frequency bands
  - 12 bands
  - 2 modes per band

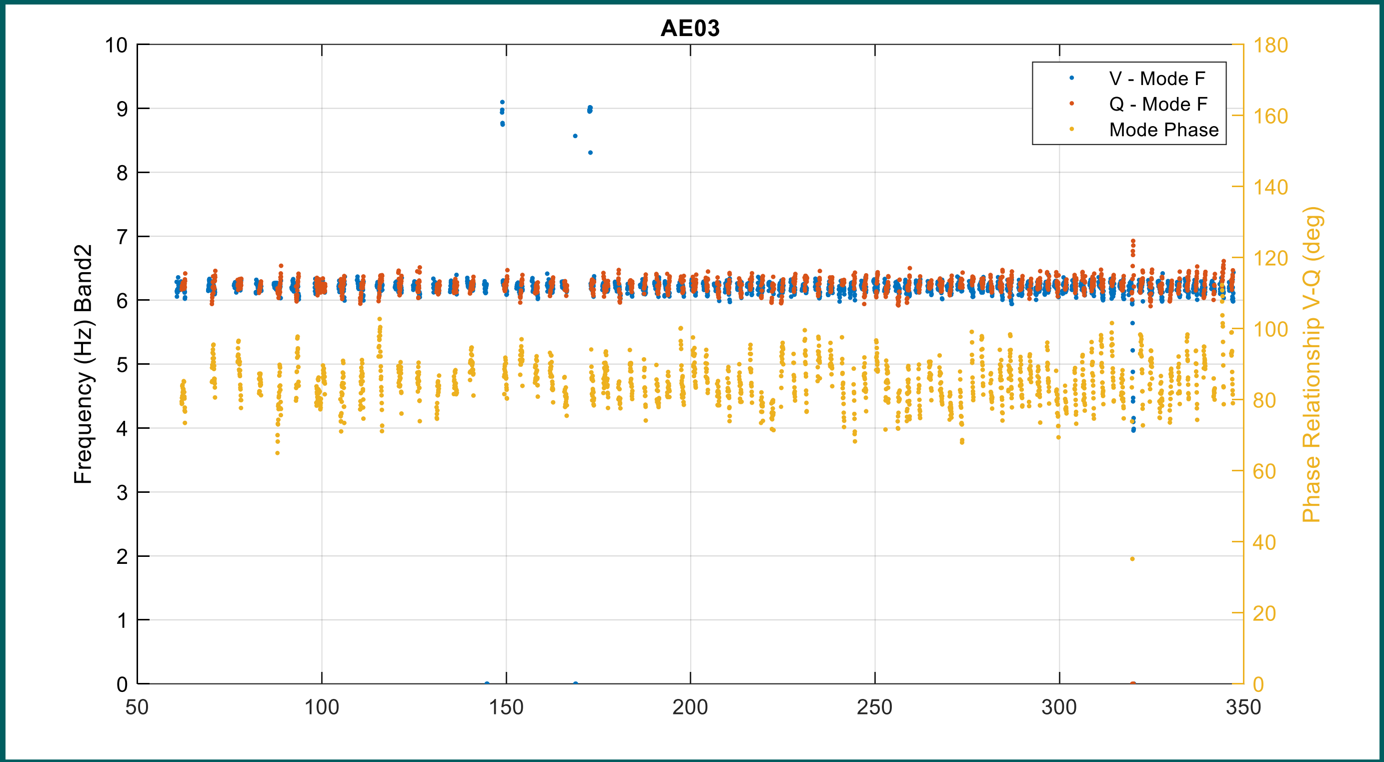


Fast Instability Detector

Phase for source/sink determination



- Results shown when FID/Thresholder triggered an alarm
- Frequency 6.2Hz
- Phase is consistently 85° (70-100°)



Waveform vs RMS/Phasor Oscillations

Classification information

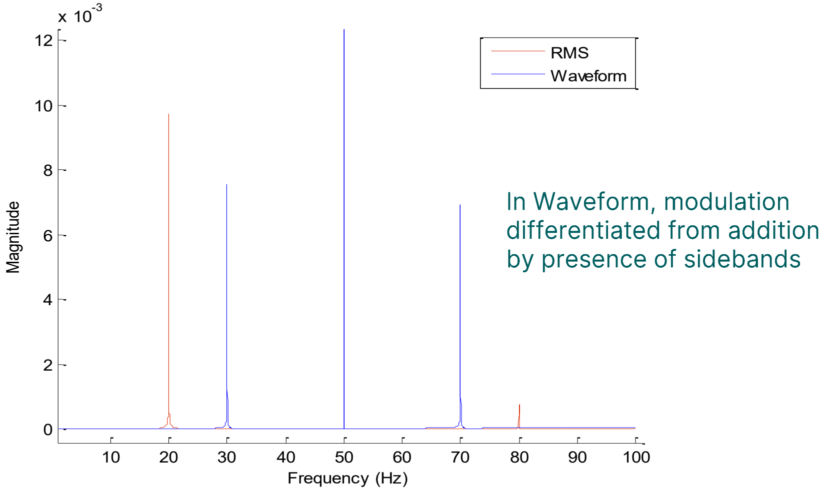
Frequency analysis of waveforms represents components differently from RMS/Phasor signals.

Added components are superimposed on the 50Hz waveform

Modulated is where the fundamental waveform changes in amplitude or frequency.

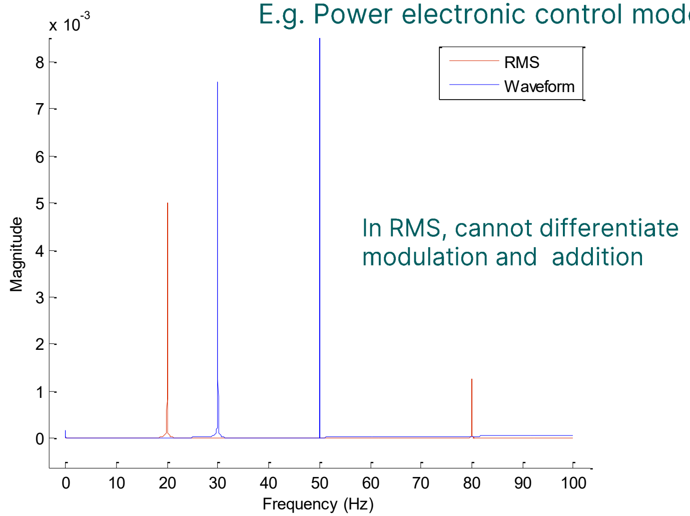
More information is captured in waveforms, but interpretation is required.

Amplitude Modulation 20Hz



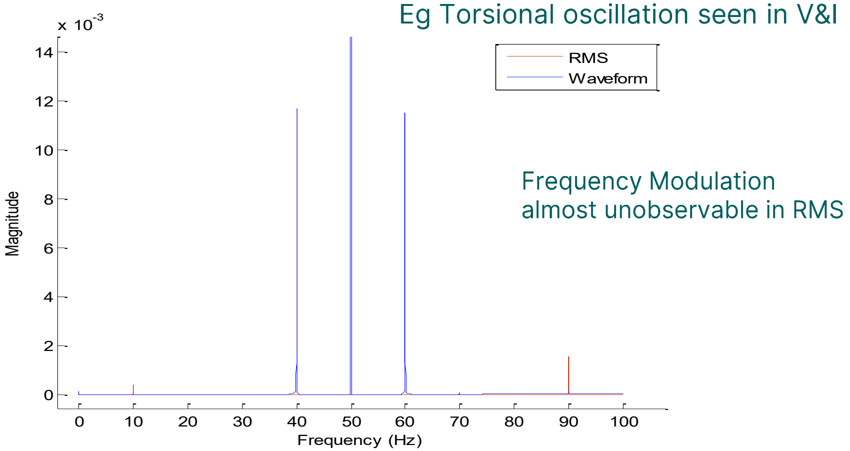
Added sub-synchronous 30Hz

E.g. Power electronic control mode

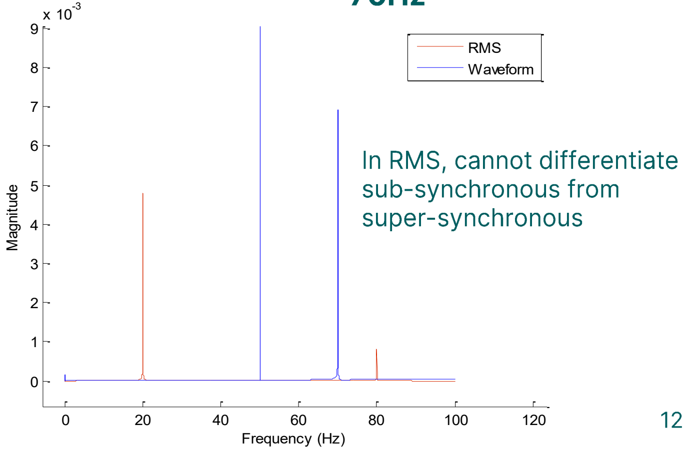


Frequency Modulation 10Hz

Eg Torsional oscillation seen in V&I



Added super-synchronous 70Hz

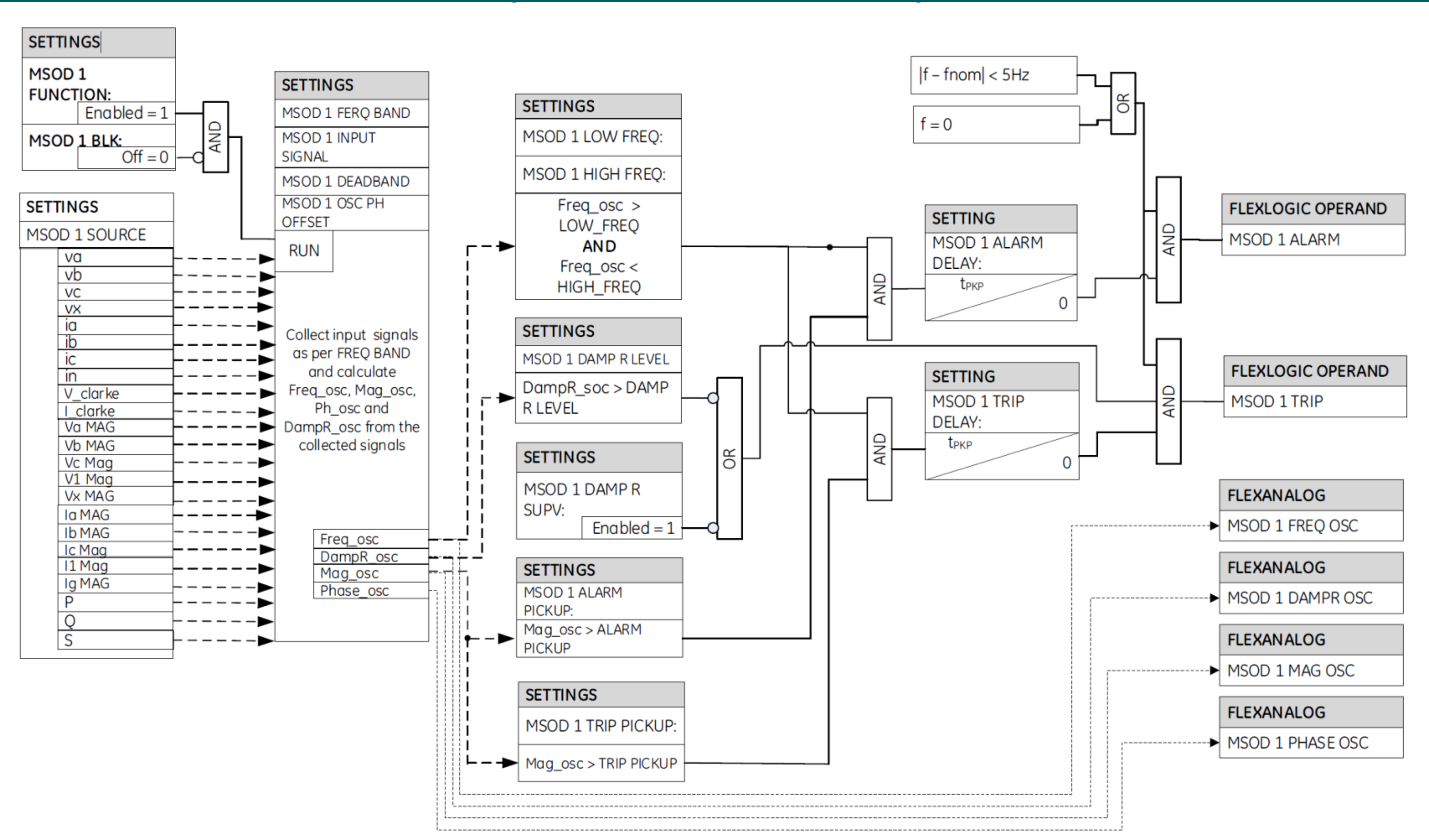


Waveform-based Local Real-Time Oscillation Detection

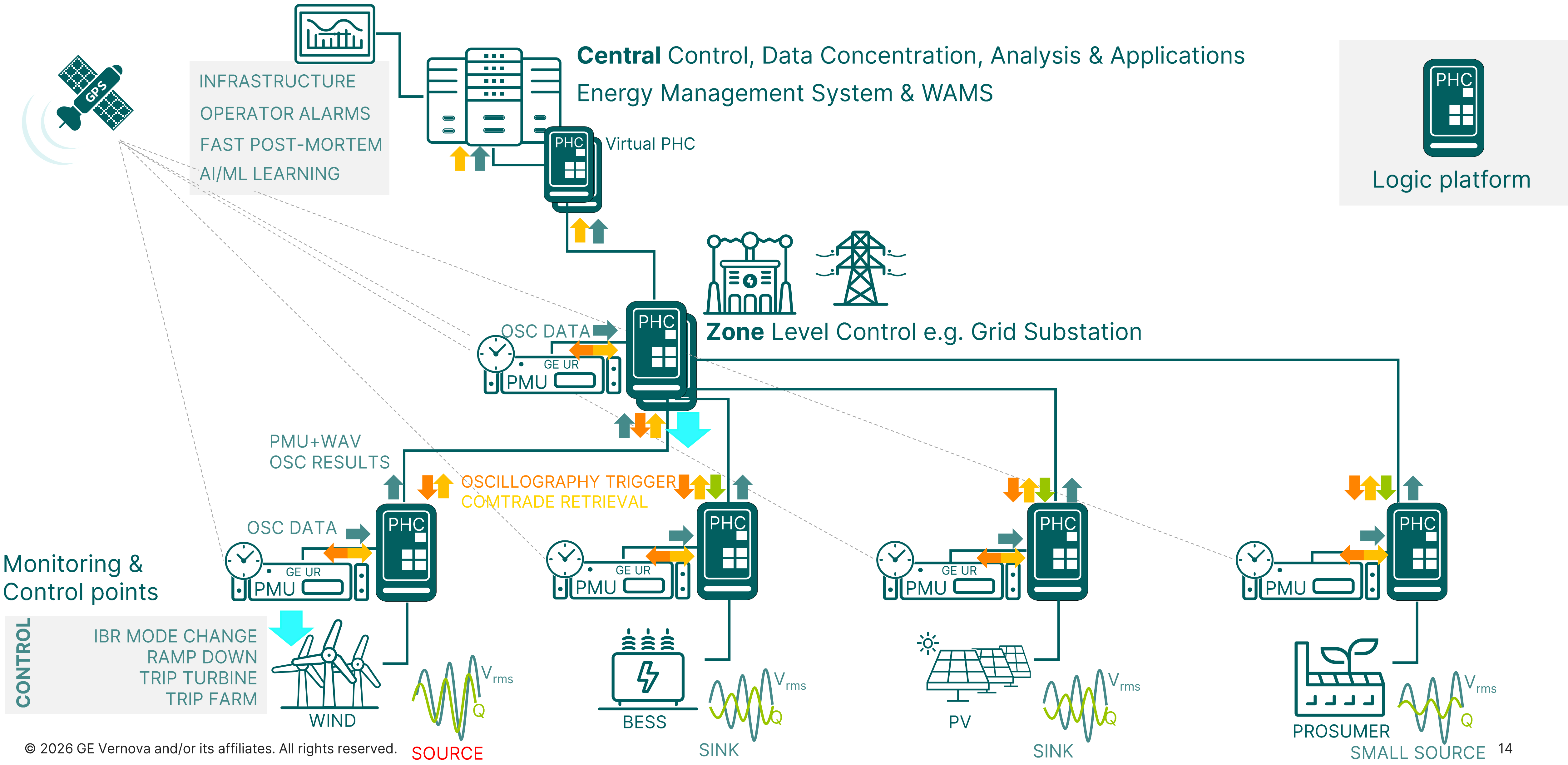
GE VERNOVA

- Local signals processed by oscillation detector (V&I)
- Local triggers can be applied on relay
- Analysis results can be included on C37.118 stream
- Key bandwidth in 10-45Hz from V&I waveforms

MSOD: Multi-range Signal Oscillation Detector



Waveform-based Monitoring & Control for IBR



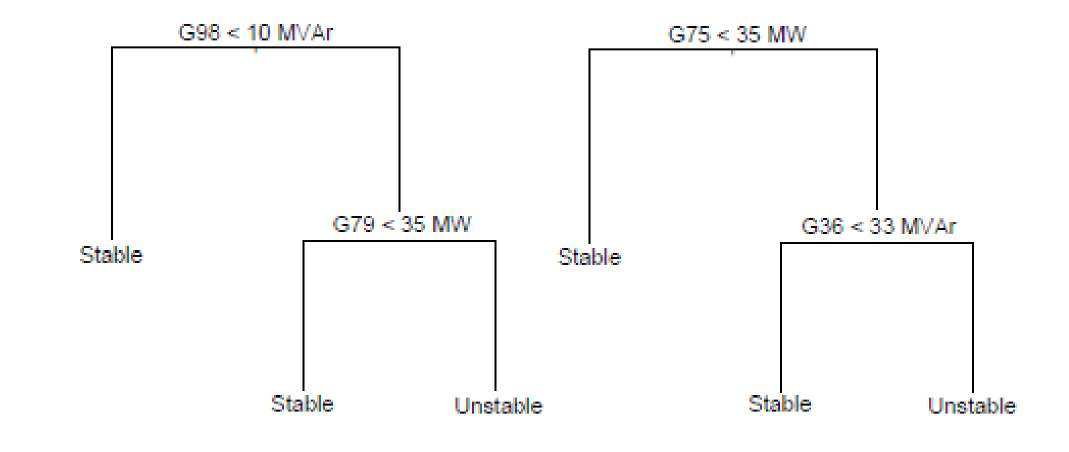
Sensitivities of oscillations to system conditions

AI/ML for further development & trial

GE VERNOVA

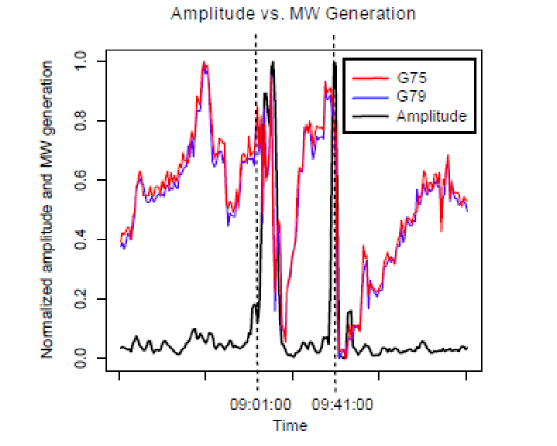
- Signal processing methods identify each mode
  - Oscillation Frequency, Amplitude and Damping
  - Geospatial distribution of oscillations
  - **Determination of areas of sources vs sinks**
- Large IBR unstable oscillations often relate to many smaller stable pre-cursor events
- Many other sources of data are useful to find influences on stability e.g.
  - SCADA P, Q, V, Topology, Exchanges; WAMS Phase Angles
  - Weather, renewable/DER conditions
  - **System strength, inertia**
  - Time, Day of week, Holiday, Seasonality
- Relationships/sensitivity guide analysts to root causes, and to short- & long-term resolutions
- Opportunity for IBR commissioning "probation period" where unexpected interactions can be resolved

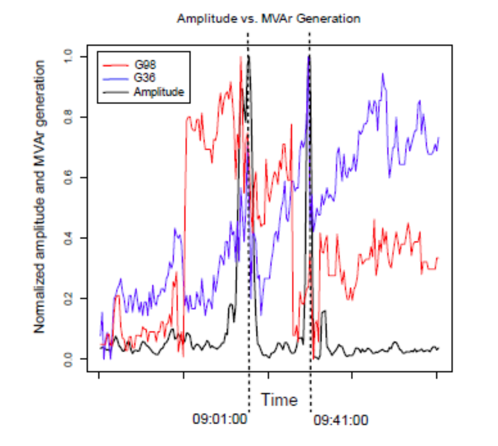
EXAMPLE P. McNabb, D. Wilson, J. Bialek, "Classification of mode damping and amplitude in power systems using synchrophasor measurements and classification trees," IEEE Trans Power Systems, vol. 28, no. 2, pp. 1988-1996, May 2013



(a) Classification tree for decay time constant

(b) Classification tree for amplitude

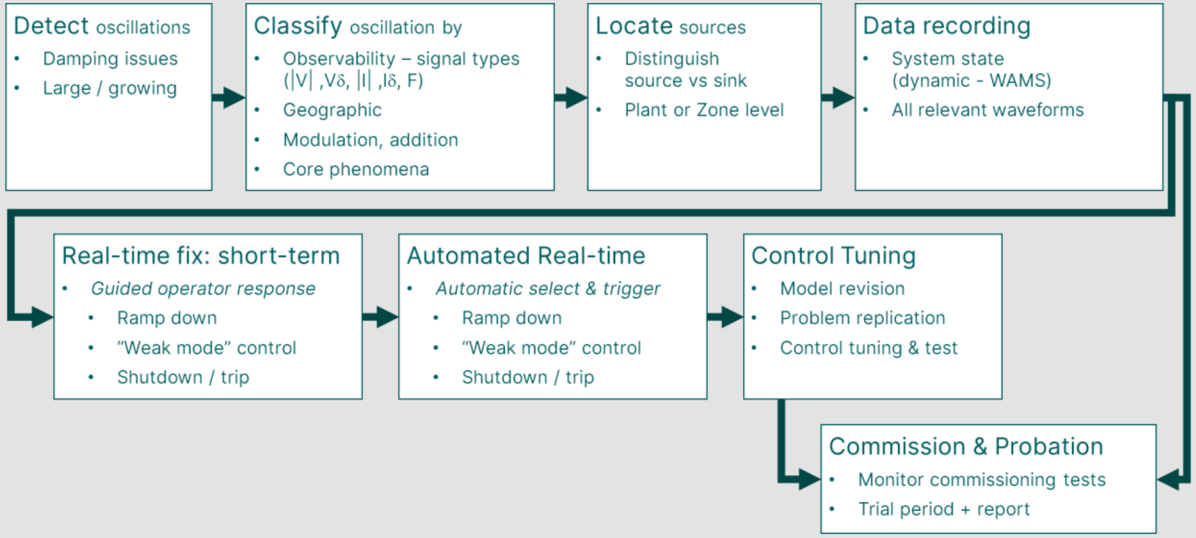




Conclusion

GE VERNOVA

- **Nature & risk** of oscillations is changing with IBR penetration
- **Operational experience** exposes IBR stability issues with suitable monitoring
- **Field-intelligent systems** are available with central orchestration
- **AI/ML tools** help to understand the underlying causes
- **End-to-end methods** address measurement–discovery–mitigation–prevention



GE VERNOVA