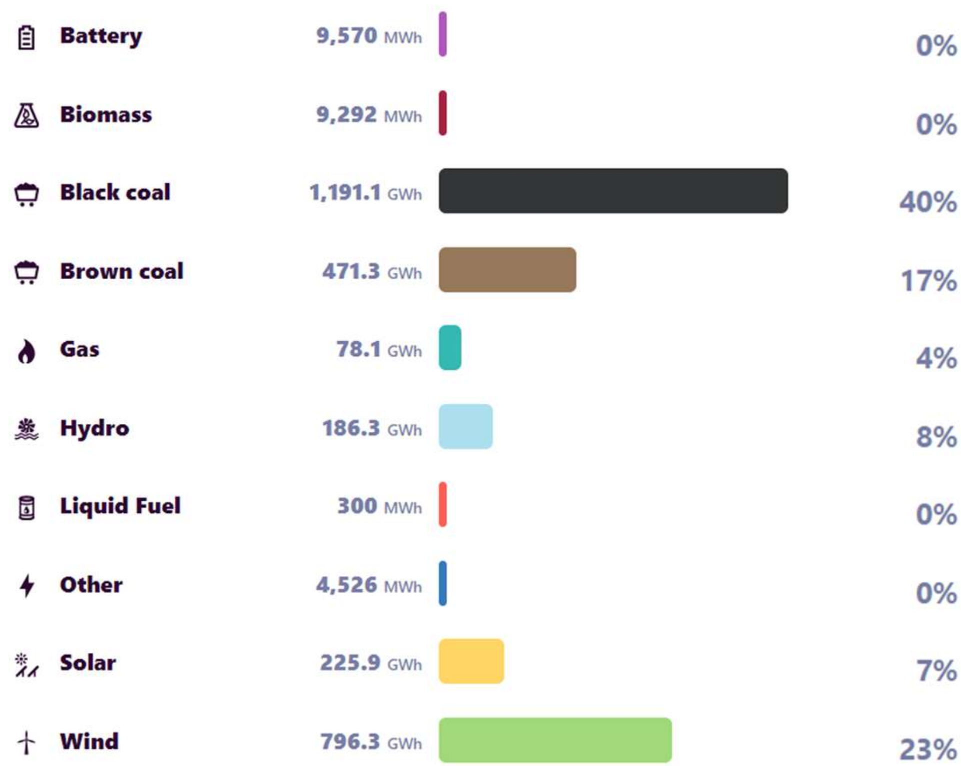
Sept/2024

Australia's Energy Transition

Power Quality in the Energy Transition

Australia’s Energy Mix

Breakdown of fuel used last 12 months
Energy served



Rapid transition from thermal synchronous generation to renewable asynchronous generation.
40 % renewable. 21GW roof top solar

National Electricity Market (NEM)

>5,000km
World's longest interconnected system

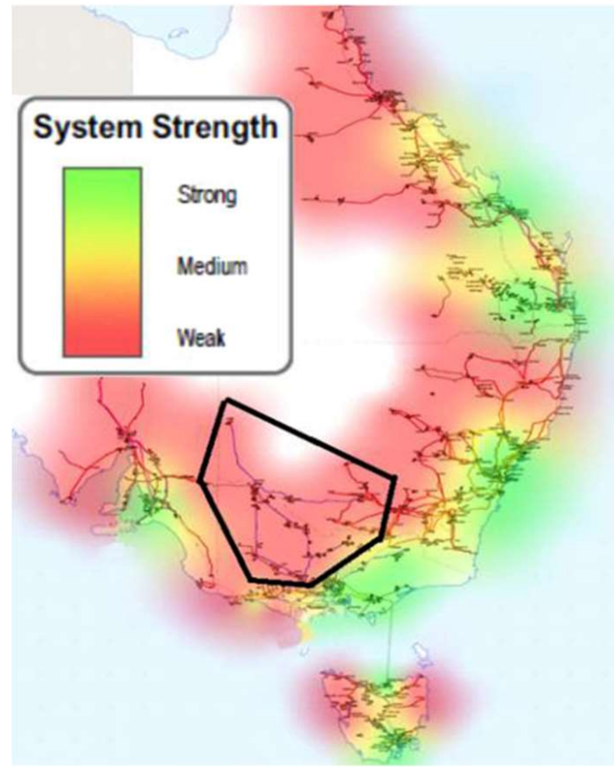
50 GW
Small in Capacity

Large load areas concentrated in capital cites separated by extremely long distances

Very distinct inter-area modes of oscillations

Very high penetration of inverter based resources including in very weak areas of the grid

Never seen before challenges in managing system strength, inertia and frequency response.



Transitioning the Energy Mix Now- 2030- 2050

Key facts and figures ('Step Change' scenario)

Storage capacity
to increase significantly
Batteries, virtual power plants, pumped hydro

NOW	2030	2050
3 GW	22 GW	49 GW

Grid-scale wind and solar
to increase 6-fold

NOW	2030	2050
21 GW	55 GW	127 GW

Distributed solar PV
to increase 4-fold
Rooftop solar, other distributed solar

NOW	2030	2050
21 GW	36 GW	86 GW

Electricity consumption from the grid
to nearly double

NOW	2030	2050
174 TWh	202 TWh	313 TWh

Gas-powered generation
to increase
While current mid-merit plants will all retire within that period

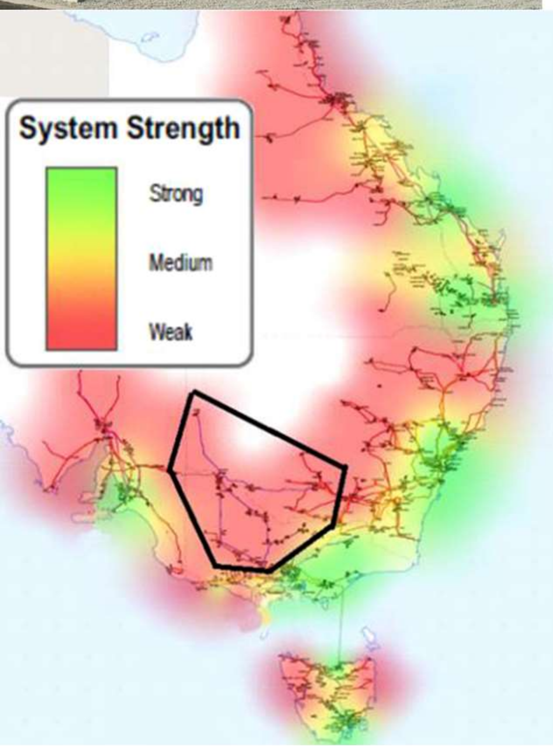
NOW	2050
11.5 GW	15 GW

Coal generation
to be withdrawn
Capacity to be retired by:

2030	2038
46%	100%

10,000 km of new transmission projects by 2050

Low Inertia



Inertia is not distributed evenly across power systems, leading to regional inertia and frequency dynamics issues.

Fast frequency response from inverter-based resources can improve frequency performance but may cause instability in weak regions.

Synchronous condensers mainly help with rate of change of frequency, while inverter-based resources are effective at arresting frequency nadirs.

Synchronous condensers are susceptible to shaft damage caused by sub-synchronous power system oscillations also common in weak grids.

Power Quality Challenges in the high to fully renewable Grid.

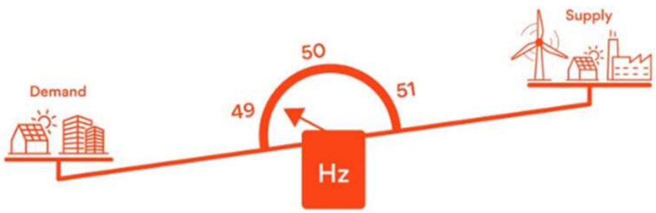
Introduction to Power Quality Challenges

- **Power Quality (PQ):** Stability of voltage, current, and frequency, Well understood in the prominently synchronised grid, but for the wholly renewable grid we don't know what we don't know.

- **Key Issues:** Reduction of **Inertia** from reduction total elimination of spinning reserve, resulting in Frequency deviations, oscillations and minimum demand in a high-renewable grid

- **Mitigation:** High speed near real time Power Quality Monitoring.
  - Role of Frequency Control Ancillary Service (FCAS) and measurement requirements
  - Sub-Synchronous Oscillations (SSO) as power quality issues

Contingency **FACS** markets



Major contingency event, such as

- Loss of a generating unit, major industrial load, or large transmission element.
- Aways enabled and paid as a service to providers for AVAILABITY.
- Occasionally used.
- New faster response requirements for the renewable Grid
- Very Fast Frequency response introduced Oct 2023

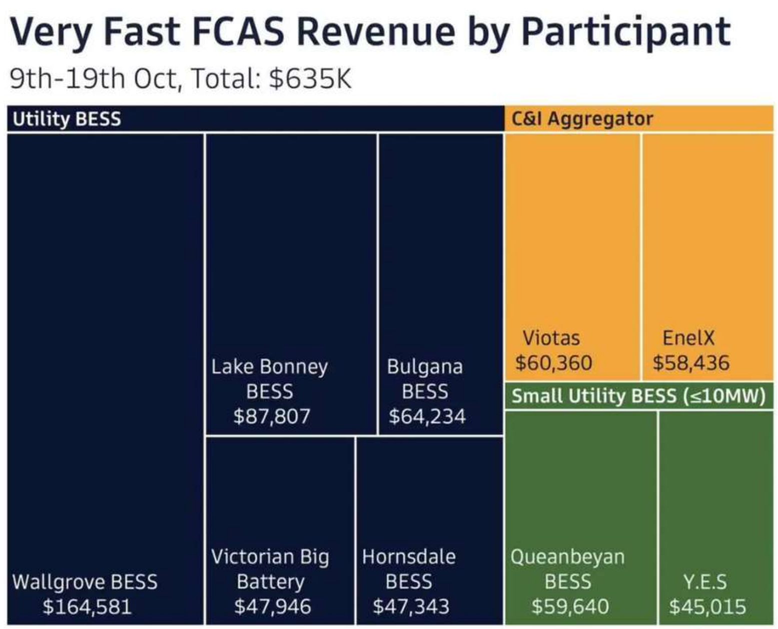
Frequency Recovery	Time from FDT	FCAS not required
Above 49.9 Hz within...	1 s	Fast Raise FCAS, Slow Raise FCAS, Delayed Raise FCAS.
	6 s	Slow Raise FCAS, Delayed Raise FCAS.
	60 s	Delayed Raise FCAS.
Below 50.1 Hz within...	1 s	Fast Lower FCAS, Slow Lower FCAS, Delayed Lower FCAS.
	6 s	Slow Lower FCAS, Delayed Lower FCAS.
	60 s	Delayed Lower FCAS.

Very Fast FCAS is a traded commodity

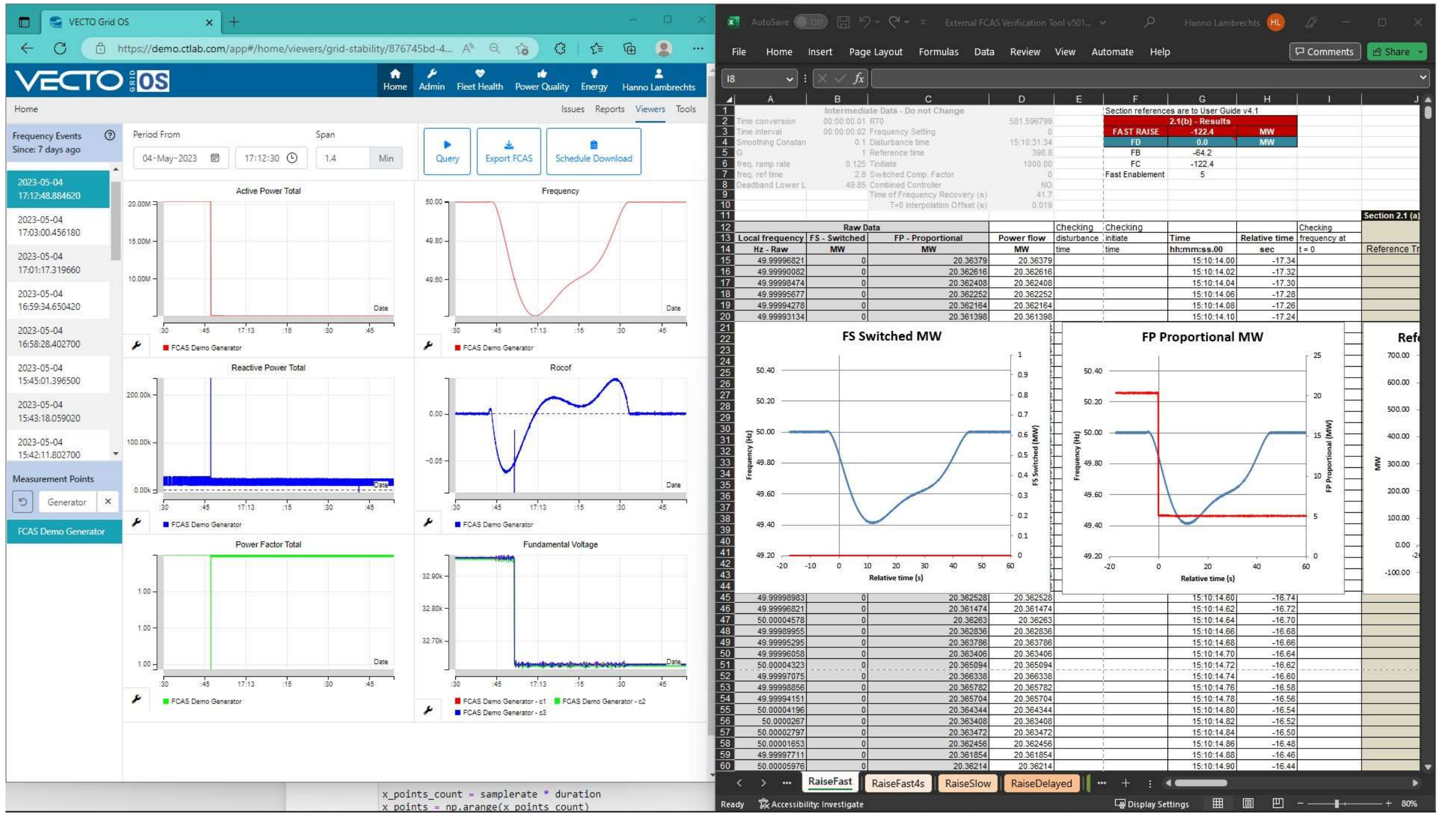
As the traditional generation is replaced by inverter-based resources, a lack of rotational inertia is now a common issue of modern power systems, which leads to **an increasingly larger rate of change of frequency** (RoCoF) following contingencies and may result in frequency collapse

ROCOF is becoming faster and deeper.

It is becoming a very lucrative market for BESS, its Aways enabled and paid as a service to providers for AVAILABITY

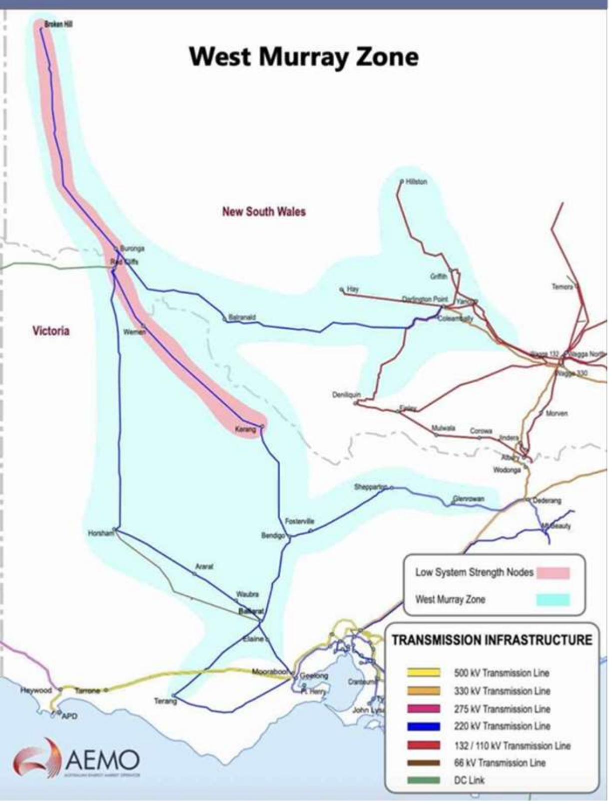


FCAS Measurement

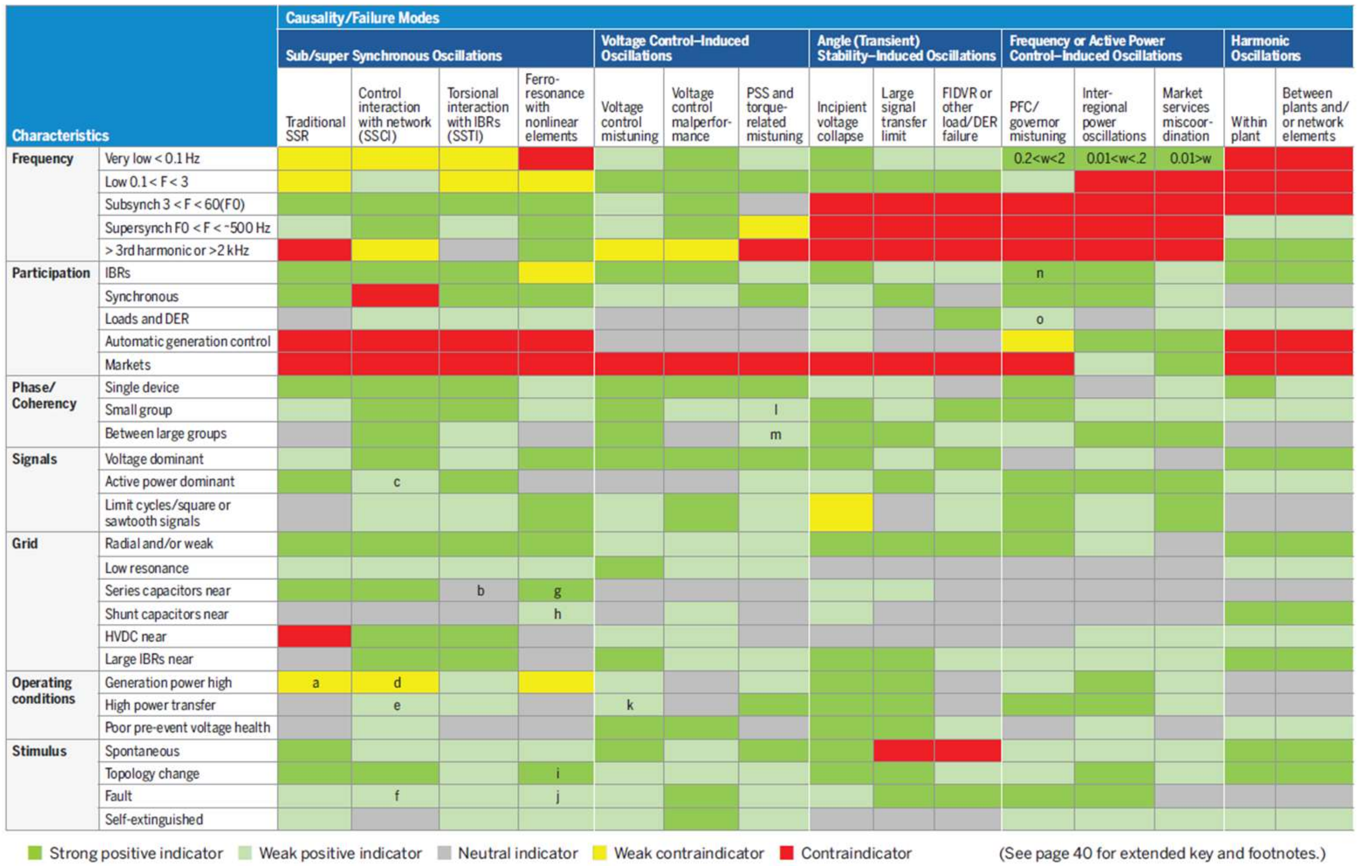


Measurement	Uncertainty	Resolution	Sampling Rate
Measurement Range of Power Flow Measurements	±0.2%	±0.02%	20 ms
Local Frequency Measurement Range	±0.0001Hz	±0.00025Hz	20 ms

Observed Oscillations



Initial Causality Screening Matrix for Determining Causality and Countermeasures for Oscillations Observed in Power Systems

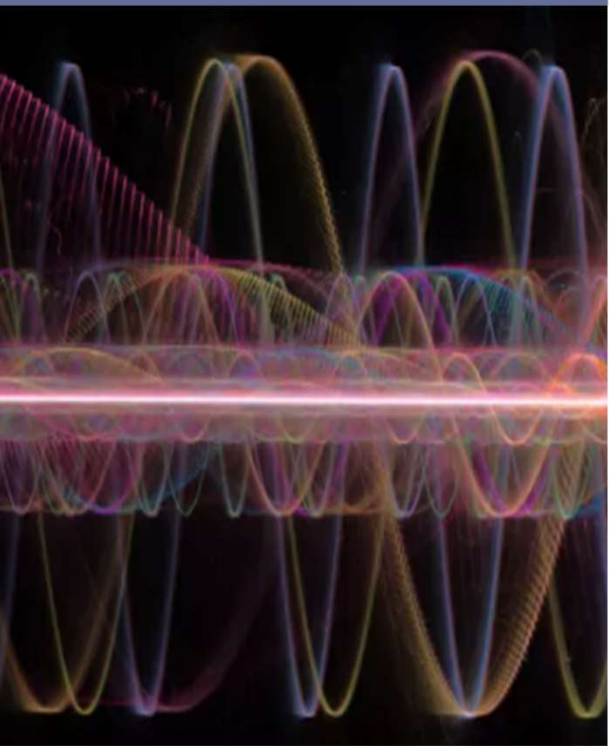


This screening matrix is an aid in collecting qualitative "symptoms" for the process of diagnosing observed oscillations. The rows correspond to the characteristics of the observed oscillation and surrounding grid conditions, while the columns represent the main categories of causes.

Nick Miller presents a practical Field Guide to diagnosing and mitigating oscillations in power systems with high levels of inverter-based resources, developed for GPST and EIG.

Diagnosis and Mitigation of Observed Oscillations in IBR-Dominant Power Systems: A Practical Guide.

PMUs and Observed Oscillations



Accurate observability of phenomena such as sub-synchronous oscillations is essential when doing Subsynchronous Control Interaction (SSCI) studies or when implementing contractual limits.

Sub-synchronous oscillations are traditionally derived from synchrophasor data streams recorded using conventional PMU devices.

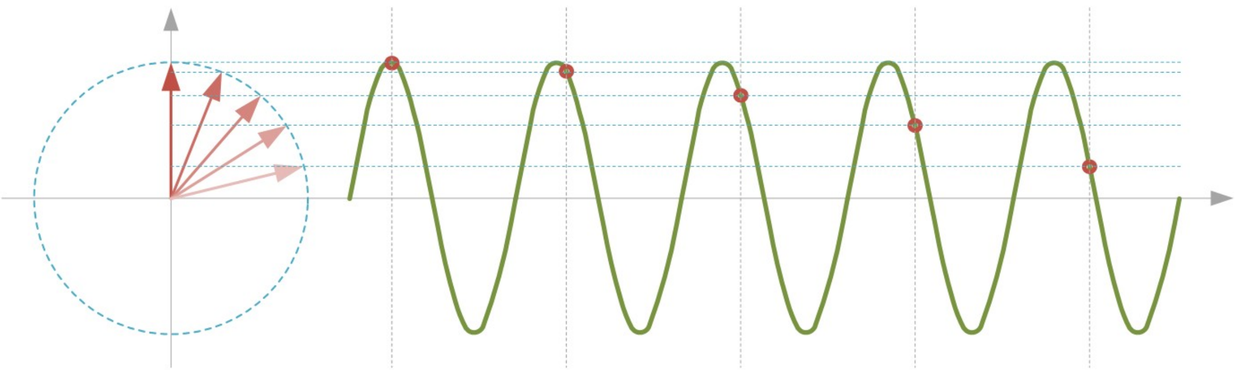
Synchrophasor measurement accuracy and bandwidth must allow for observability of oscillation parameters from DC up to ±40Hz.

However; In many cases the accuracy of P-class devices are inadequate while M-class devices are too slow to detect higher frequency oscillations typically associated with IBR instability (> 25Hz).

To combat the limitations associated with PMU data streams, CT LAB has developed an algorithm to accurately detect and quantify the complete Synchronous Oscillation Phasor

oPMU

SW Module



It is NOT PMU based

It is a time synchronised phasor

- Amplitude
- Phase angle
- Frequency
- ROCOF

Updated once every 20ms

Simultaneously tracks up to 3 phasors in 3 x frequency bands

Can stream phasor data via PMU protocol

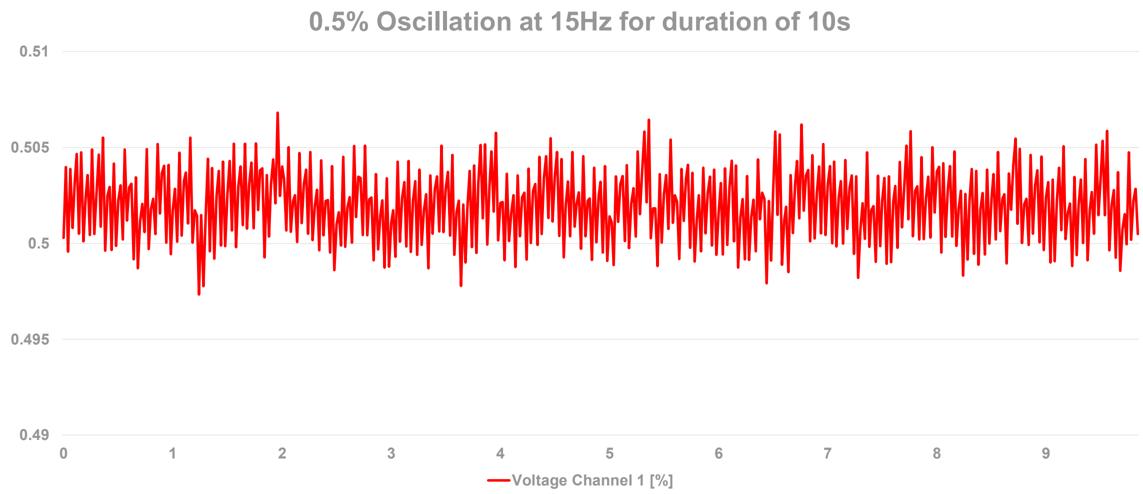
Recorded as 20ms interval trends

Or as event with pre- and post-event data

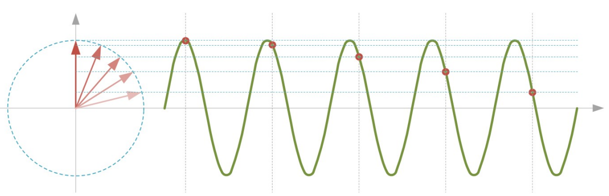
- Time Synchronised Waveforms
- RMS & Phasors
- Synchrophasors

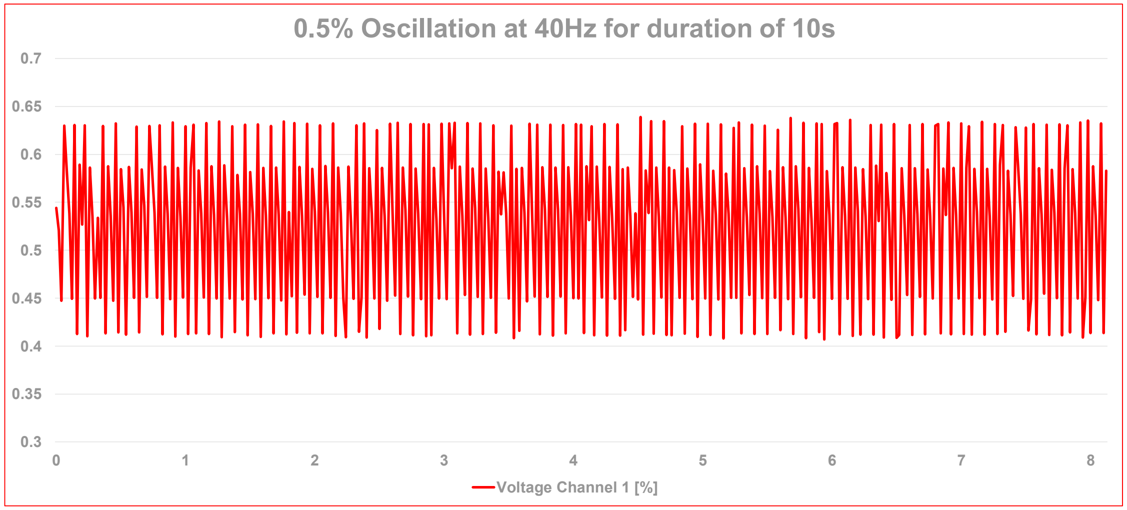
oPMU

Accuracy & Bandwidth



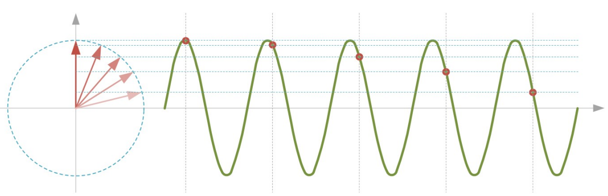
The maximum theoretical detectable oscillation frequency of a standard PMU's is <25Hz (due to the Nyquist limitation)



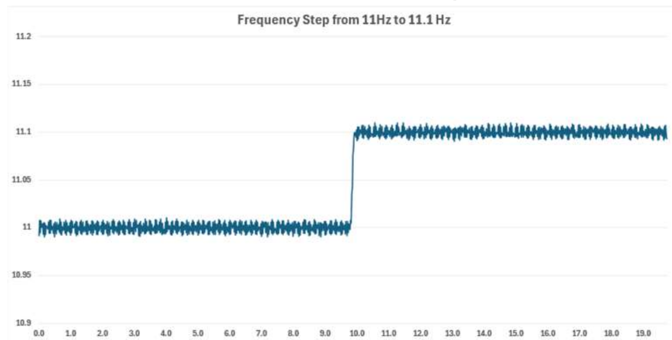


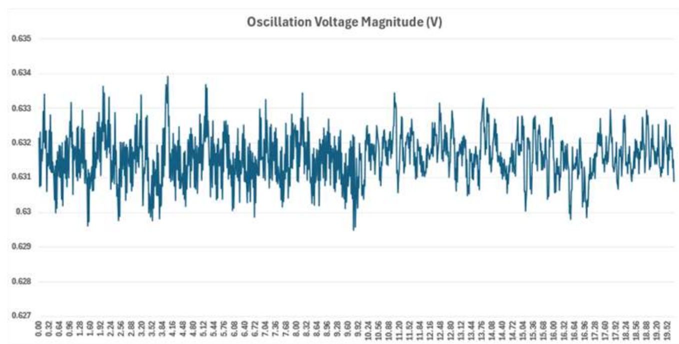
oPMU

Frequency Step Response

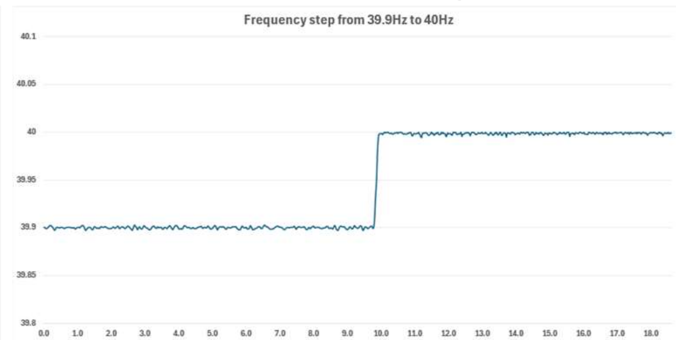


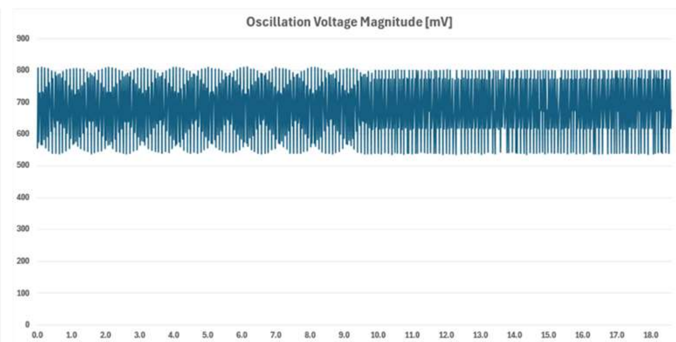
Step from 11Hz to 11.1Hz – 1% Magnitude





Step from 39.9Hz to 40Hz – 1% Magnitude

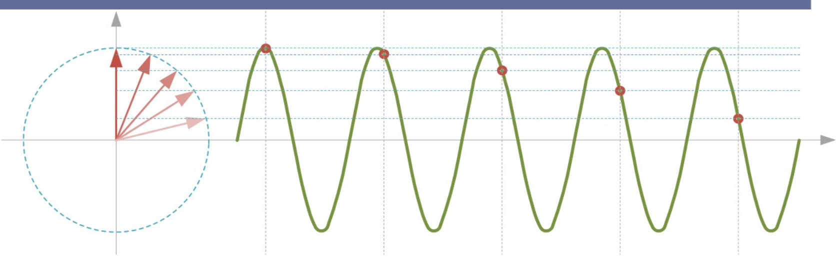


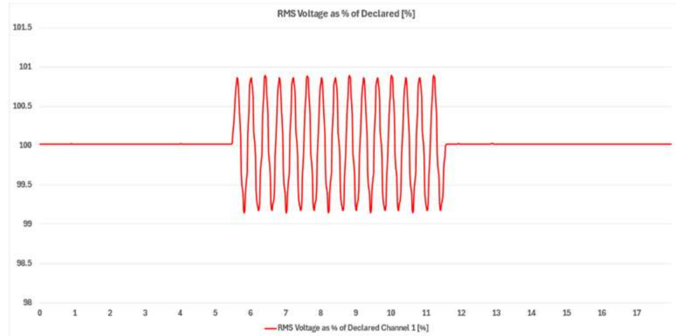


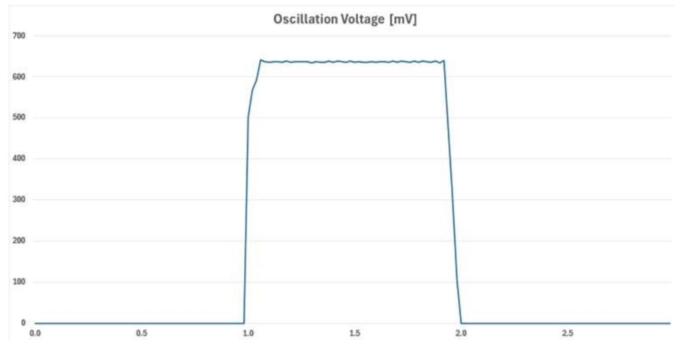
There should be no overshoot, and the step should not be under damped.
A 0.1Hz frequency step was performed at 11Hz and at 40Hz

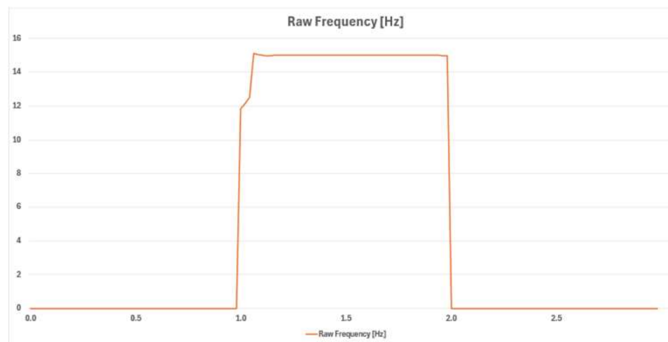
oPMU

Event
1% of 63.5V
15Hz for 1s





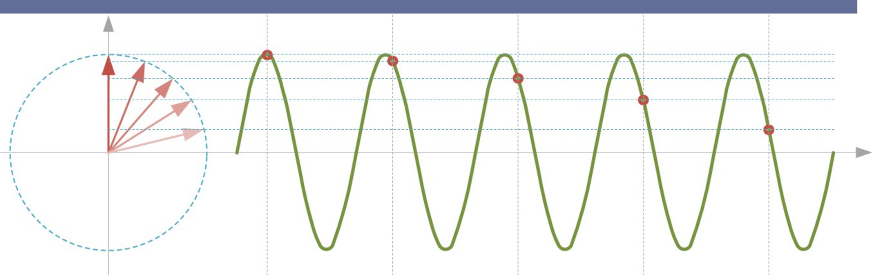




- RMS waveform of the 1% oscillation super positioned on top of the 63.5V 50Hz fundamental
- The middle graph presents the amplitude of the oscillation event.
- The bottom graph presents the frequency of the oscillation event.

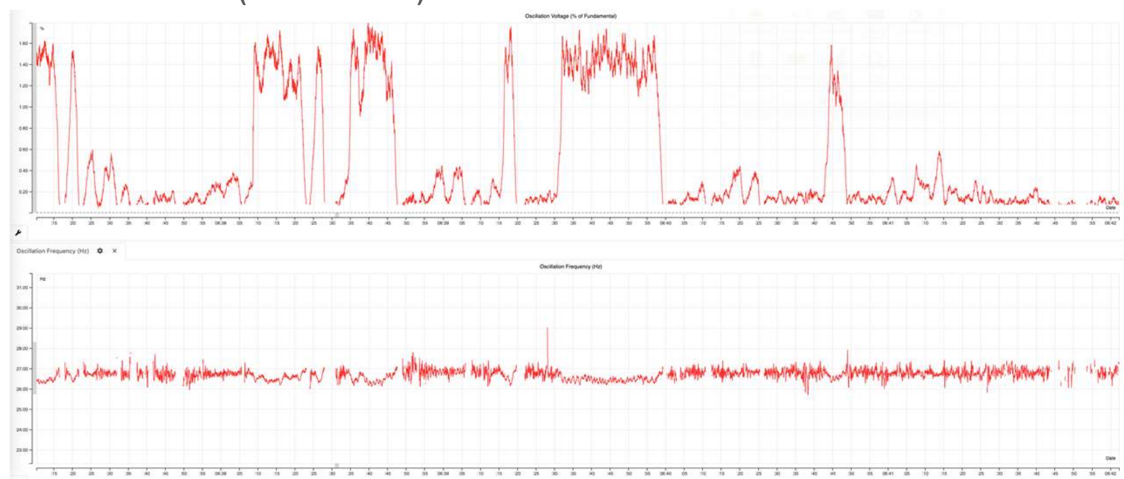
oPMU

Field Recorded
Trend & Event

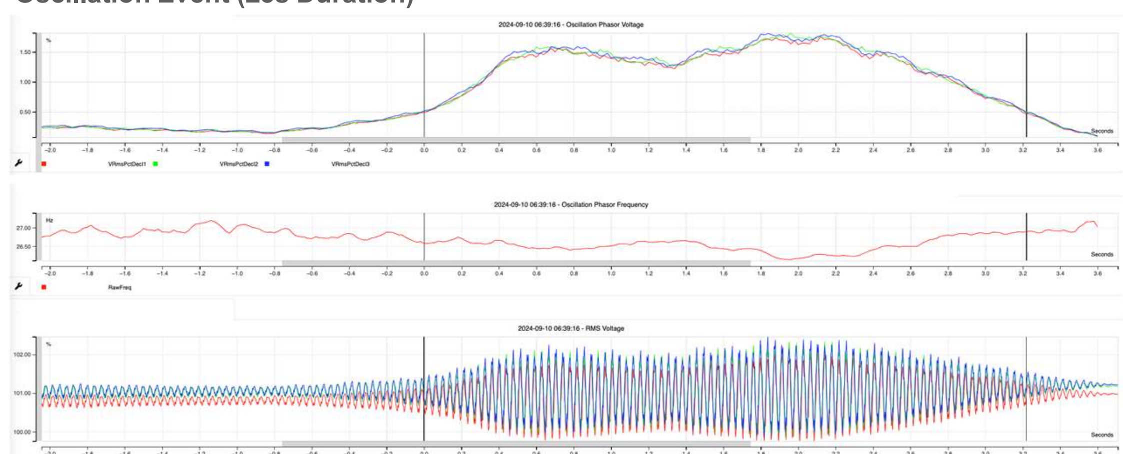


- Many of the oscillation events has a duration of <5s.
- The long one has a duration of ±30s.
- The peak magnitude is as high as 1.8% of the fundamental
- The frequency of the oscillation stays fairly constant at ±27Hz

Oscillation Trend (20ms Interval)



Oscillation Event (±3s Duration)



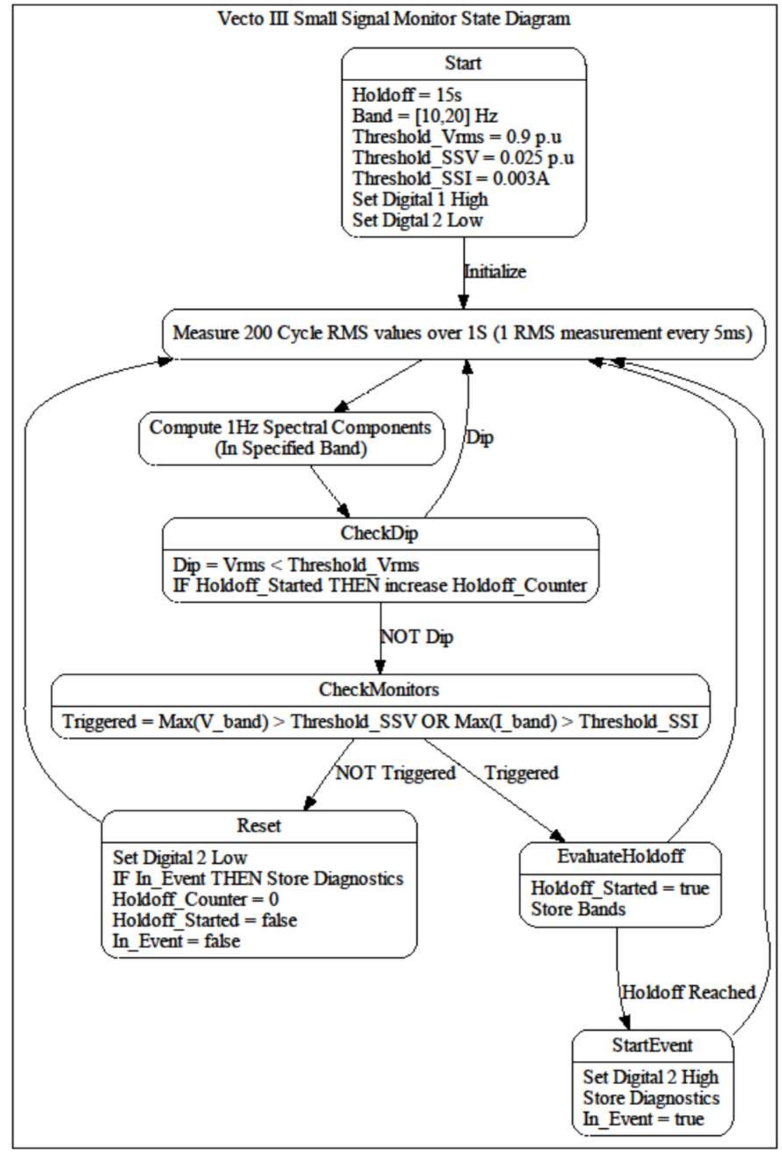
oPMU Applications

Threat of torsional shaft damage caused by oscillations

oPMU deployed to accurate measure oscillation in the band 15 to 20 hz

State monitor developed in conjunction with AEMO to avoid false tripping due to DIPS.

oPMU triggers relay control to isolate syncon in case of major oscillation event.



oPMU Applications

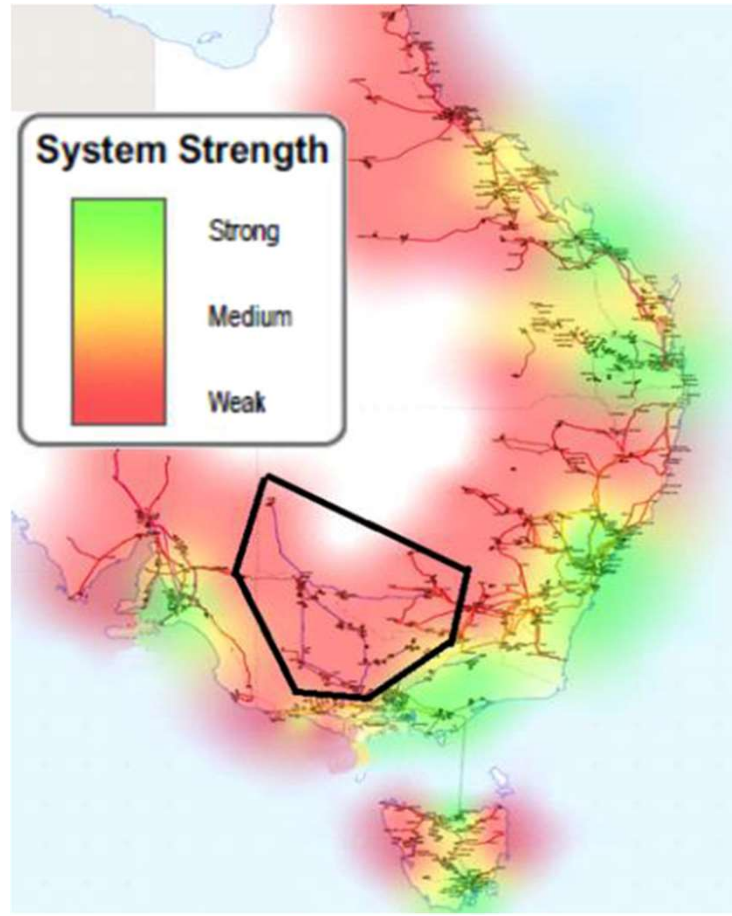
Market Operator imposed risk of 50% plant curtailment

oPMU deployed at Solar Farm to accurately measure and trend oscillation in the band 10 to 43 hz

oPMU accurately detected and trended 27 hz oscillations

oPMU Scada command implemented to trigger invertor flight recorder control and feedback parameters during oscillation.

Analyse setting and retune



As the Grid transitions to 100% renewable energy, PQ monitoring solutions need to be adaptable to the changing environment and new Phenomena

Waveform Synchronised (±100ns)

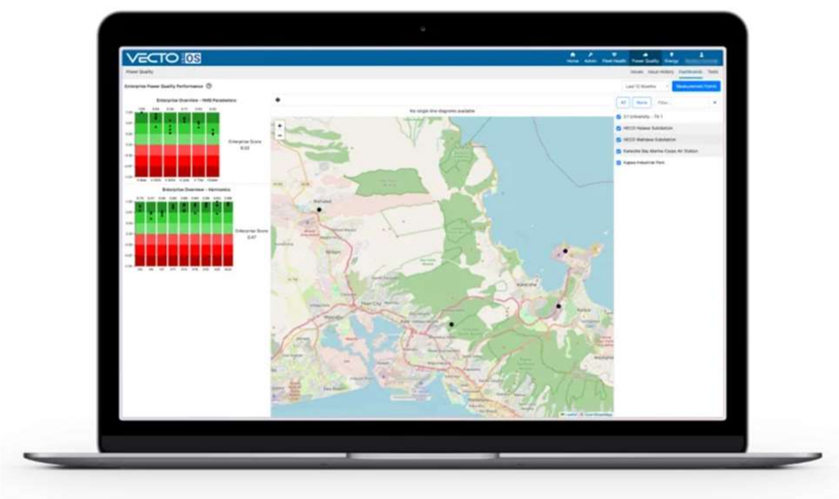
Broadband

- 1.5MHz fixed sampling rate
- 500kHz analog bandwidth

Multifunction

- PQI (ED3.1 – Class-A)
- PMU (Simultaneous M & P Class)(Fast & Accurate)
- oPMU (DC-43Hz)
- Automation (20ms update) (Plant controller input)
- Metering

Always online with Realtime visibility



Enterprise class Big Data platform

“Live” System (Data available in near real-time)

Highly interactive web interface

Designed from ground up supporting
- >10,000 devices
- >100 simultaneous users

Permanent secure IP based connectivity

QUESTIONS