



DIgSILENT Pacific

Power system engineering and software

Emerging conventional generation performance issues in a changing grid

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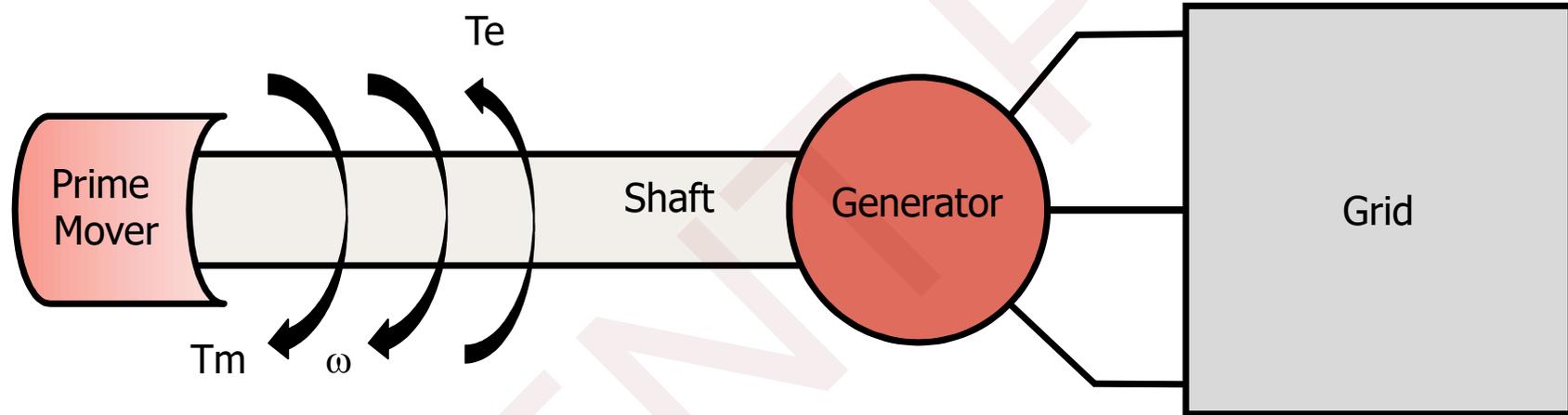
Overview

- Motivation
- Transient and small signal stability background
- Case studies:
 - Generator performance during a recent system frequency event
 - Increased VRE generation on small signal stability
 - Low inertia generator transient stability
- Findings

Motivation

- A changing grid – frequency and severity:
 - System frequency response to disturbances
 - Weather events and severe disturbances
 - System load and generation profile
- Conventional generators still have a role to play in the grid
- Their performance has to be considered

Synchronous generator dynamics



- T_m = mechanical torque
- T_e = electrical torque
- ω = rotational speed
- H = inertia

$$2H \frac{d\omega}{dt} = T_m - T_e$$

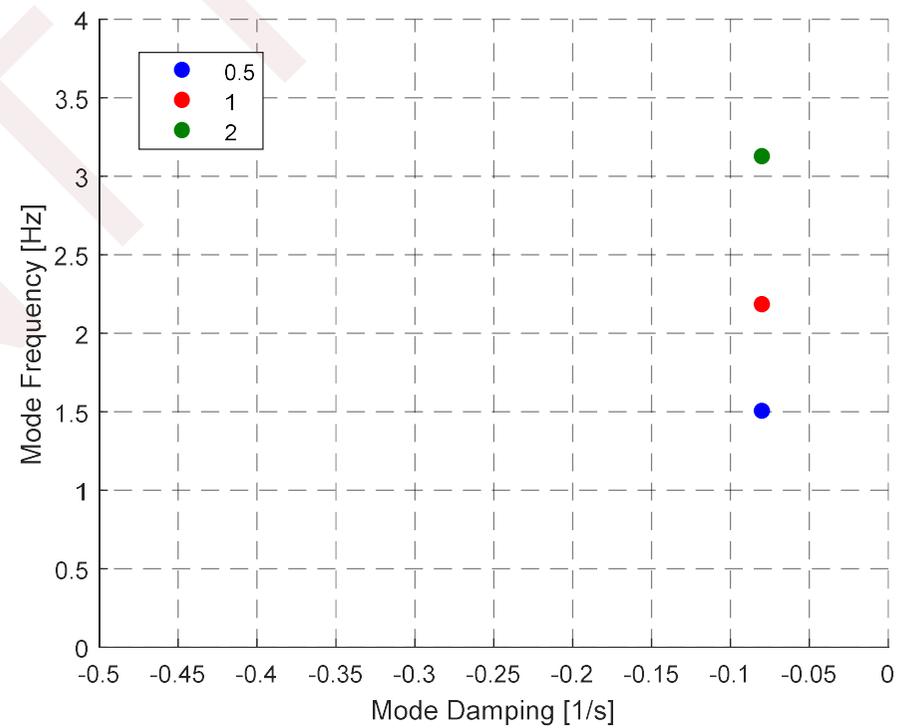
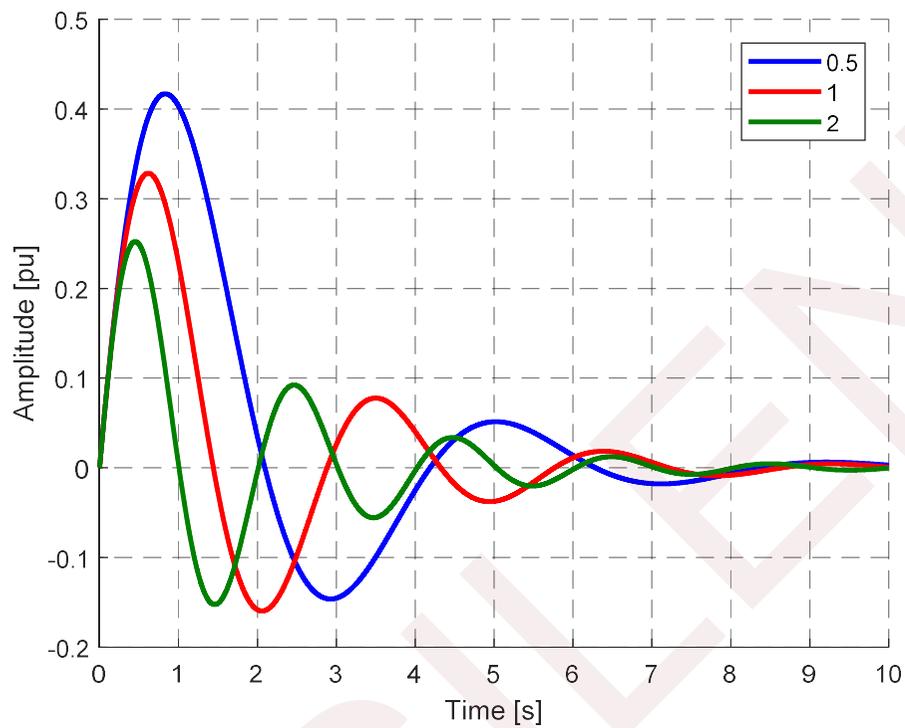
Synchronous generator stability

- **Transient stability** primarily concerned with immediate effects of large signal disturbances on power system synchronism
- Following a disturbance, the generator speed and P_e will vary around its operating point, defined by the “swing equation”

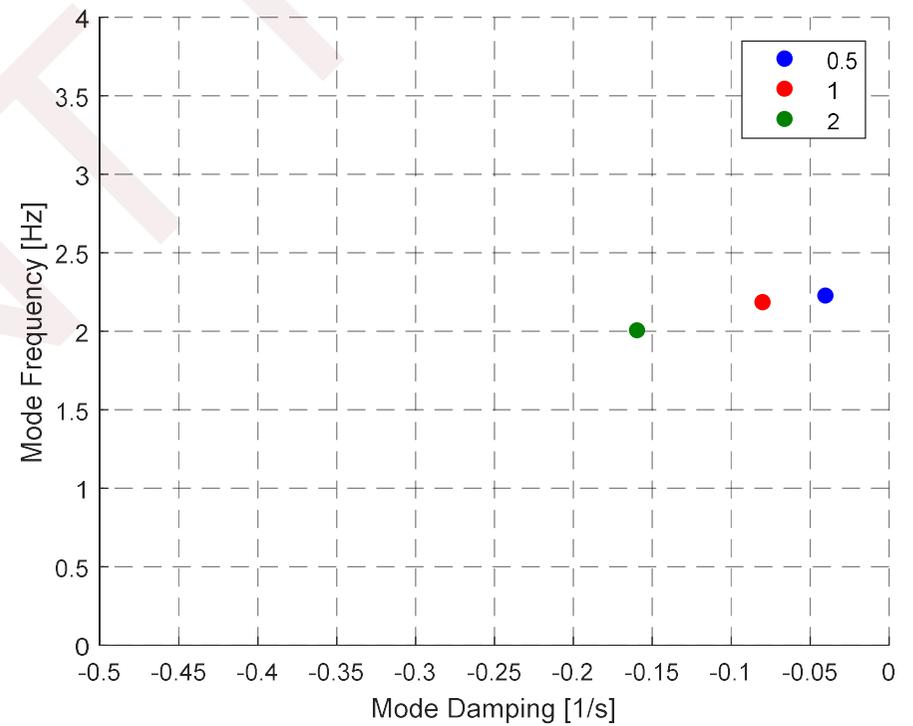
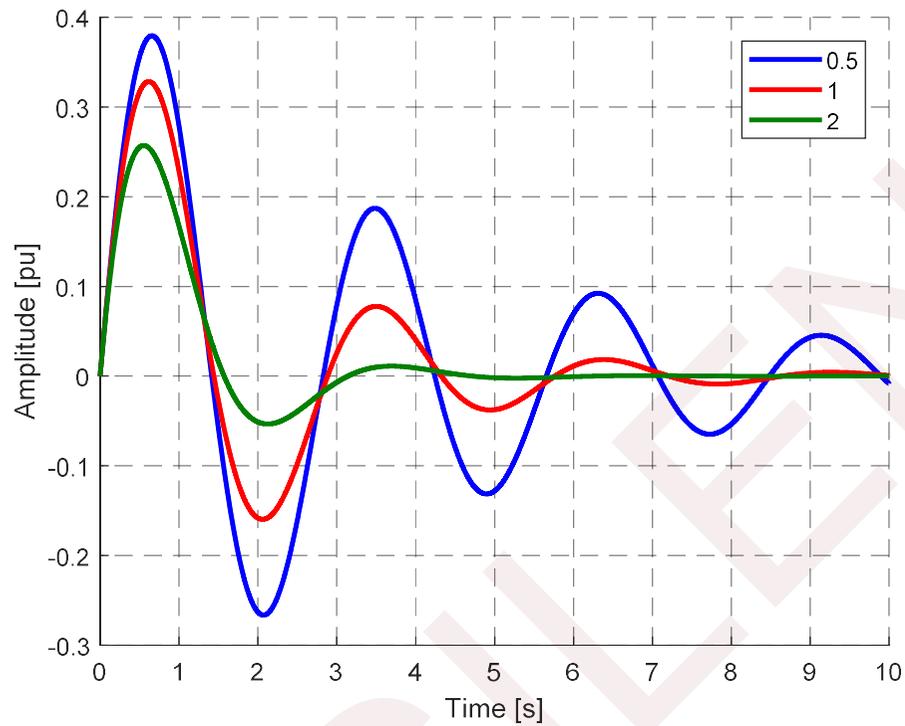
$$2H \frac{d\omega}{dt} = T_m - T_e$$

- **Small signal stability** is defined by the ability of a power system to maintain synchronism under small disturbances (or perturbations)
- Useful to decompose electrical torque into:
 - Damping torque
 - Synchronising torque

Effect of synchronising torques



Effect of damping torques



Key synchronous generator components

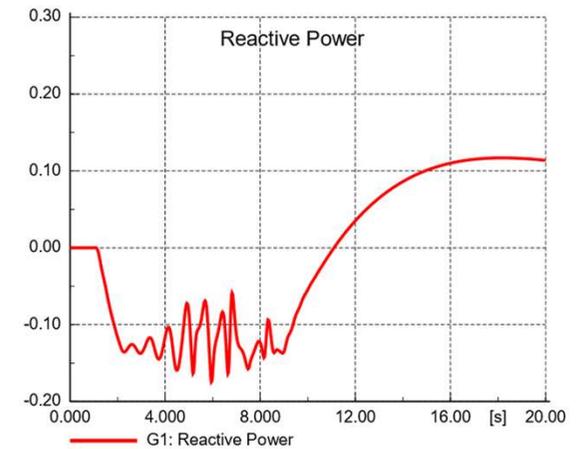
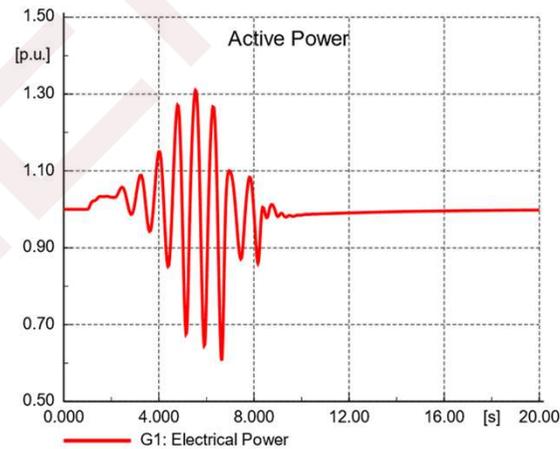
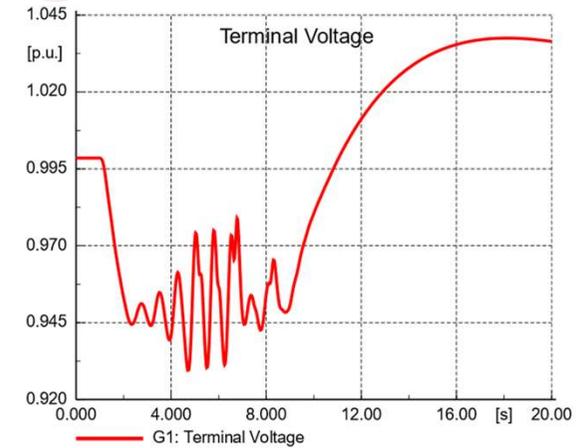
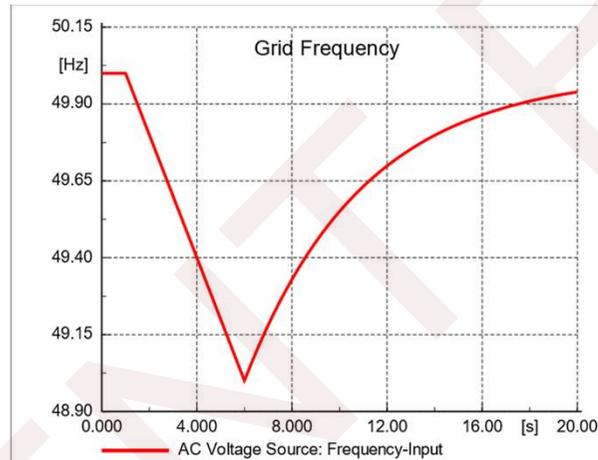
- Generator inertia
 - Changes acceleration rate and frequency of oscillations
- Automatic Voltage Regulator (AVR)
 - Controls generator voltage by changing excitation
 - Improves transient stability by increasing synchronising torque
 - Can degrade small signal stability by reducing damping torque
- Power System Stabiliser (PSS)
 - Controls damping by applying bias signal to AVR
 - Improves small signal stability by increasing damping torque
 - Uses power, speed or frequency measurements
 - Do not respond to undesired stimuli
 - Do not overly impact voltage control

Case study: legacy PSS performance

- Generator performance during system event
- Analysis of behaviour during event
- Analysis of PSS damping performance
- Potential solutions

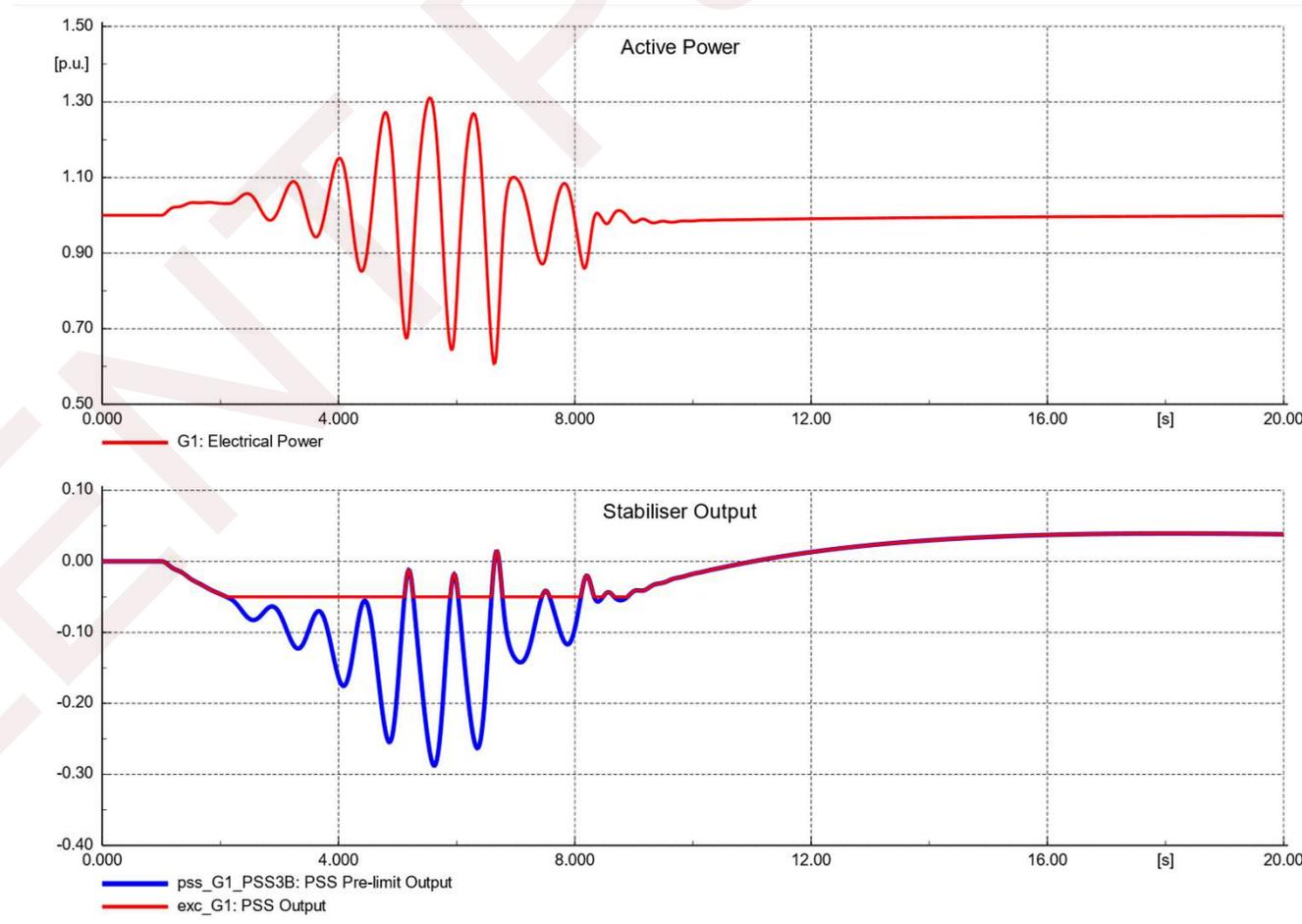
Performance during event

- Lightning event causes interconnector tripping and islanding
- Major frequency disturbance and load shedding
- Lightly damped active power oscillations



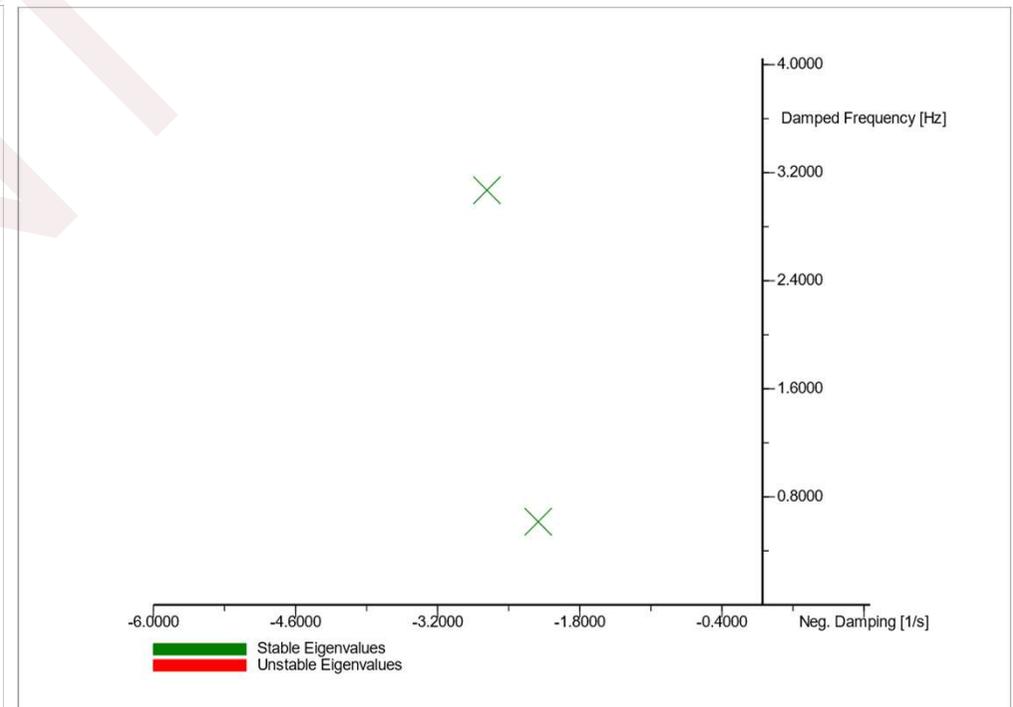
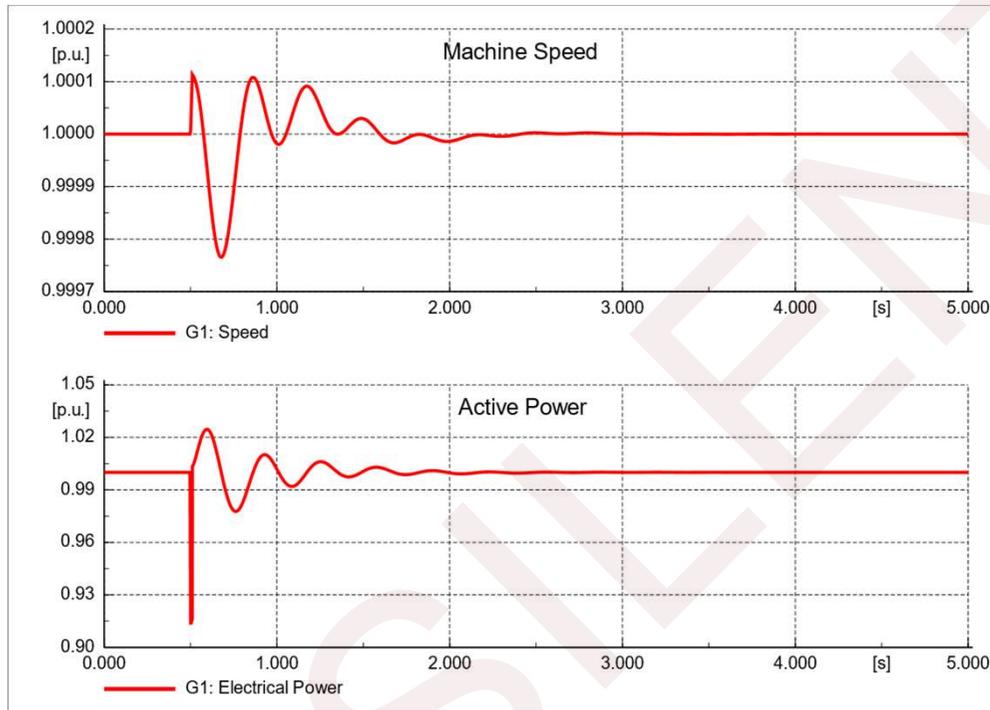
Model performance assessment

- Simulation using model of generating system revealed similar performance
- PSS output saturates at negative limit during event
- Large negative bias applied
- PSS not available for damping
- Dual input PSS (PSS3B) with speed and power inputs



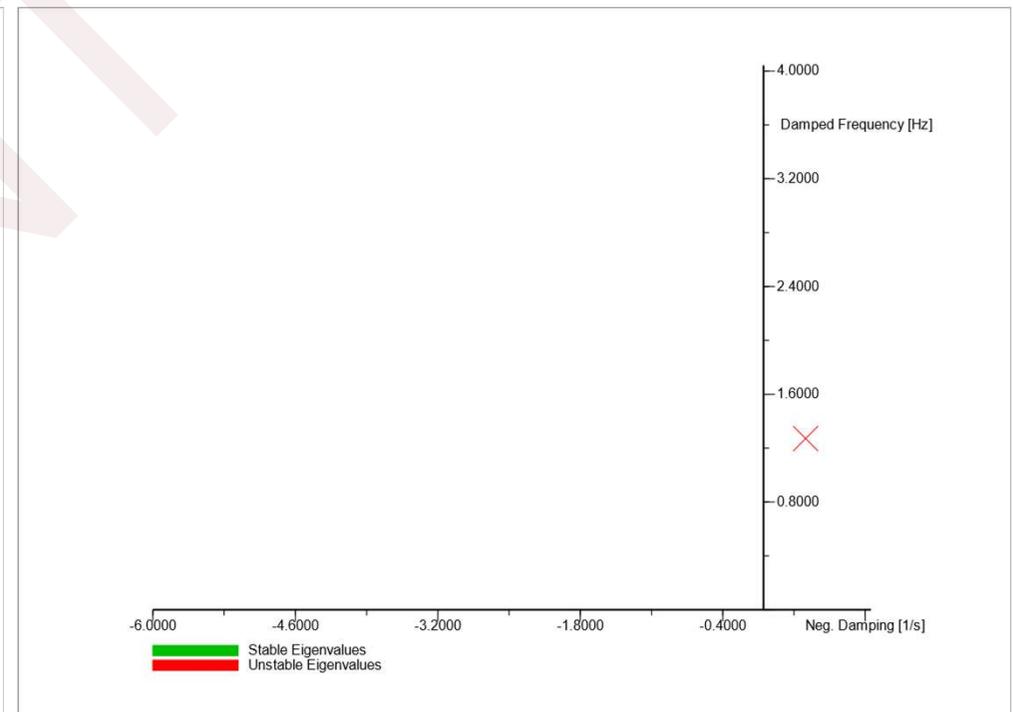
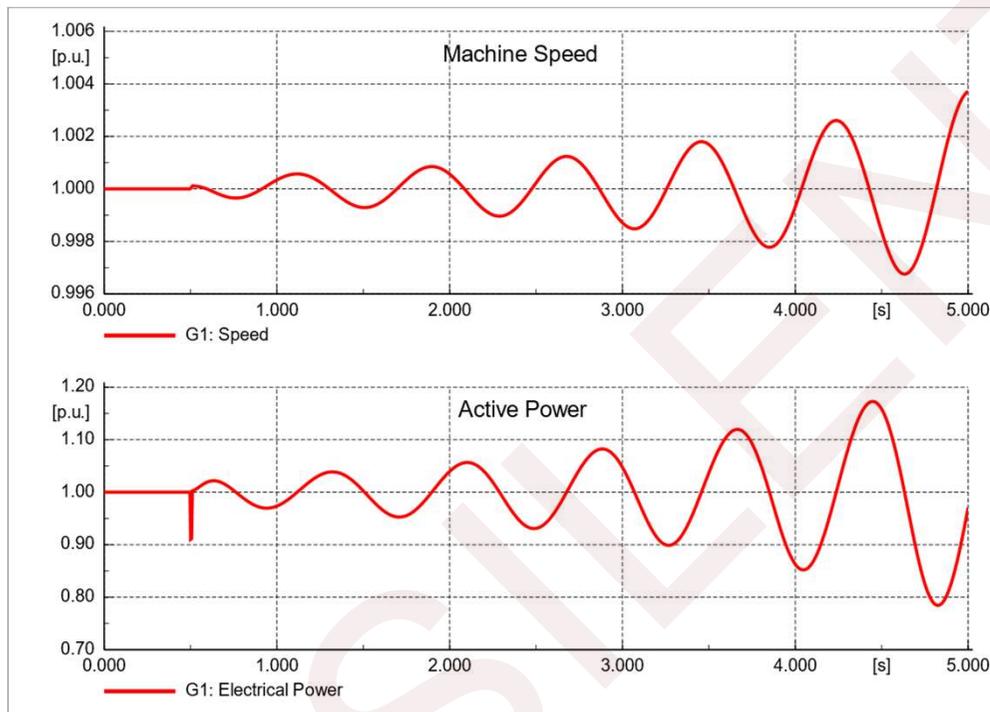
PSS performance analysis – normal conditions

- Stable, well damped

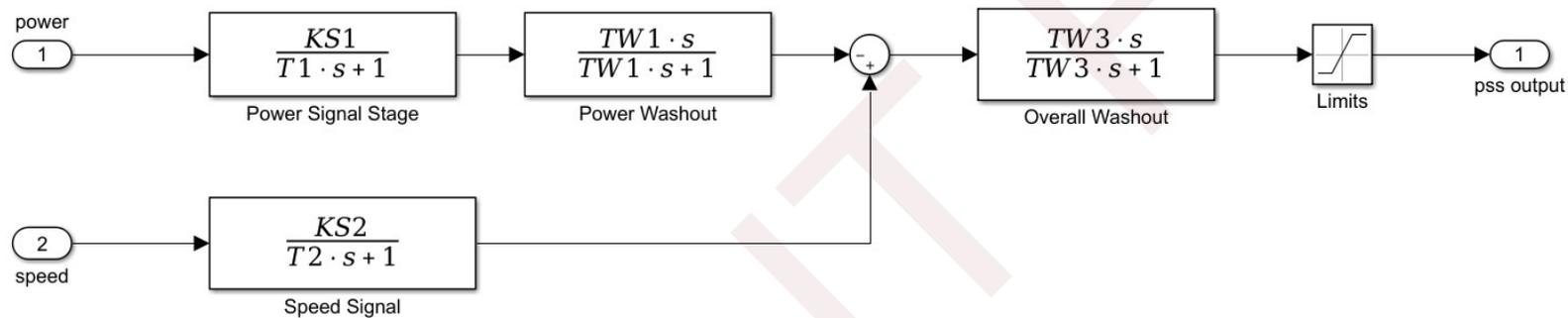


PSS performance analysis – emulated under-frequency conditions

- Unstable, undamped oscillations



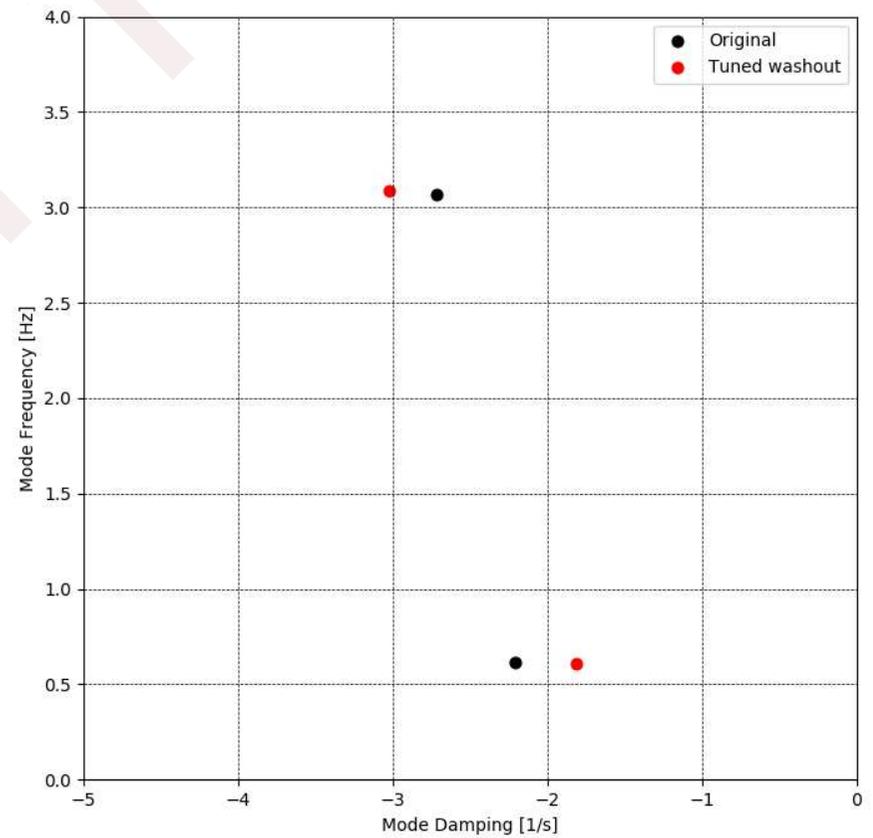
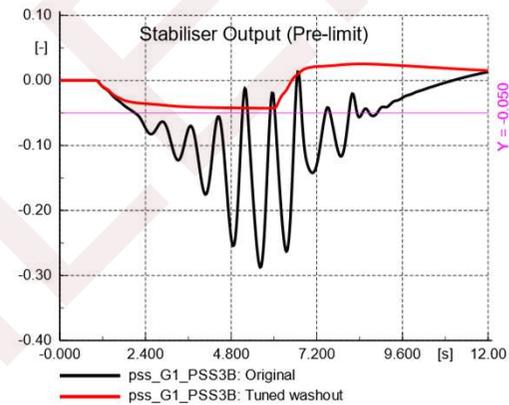
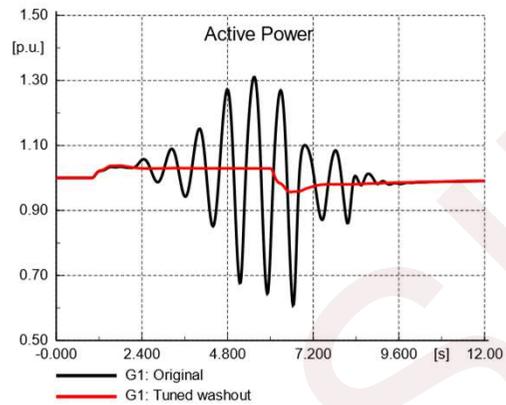
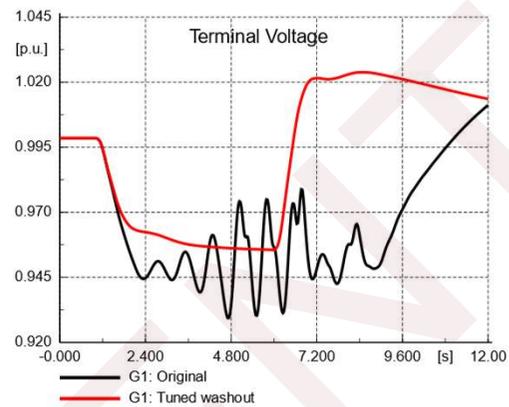
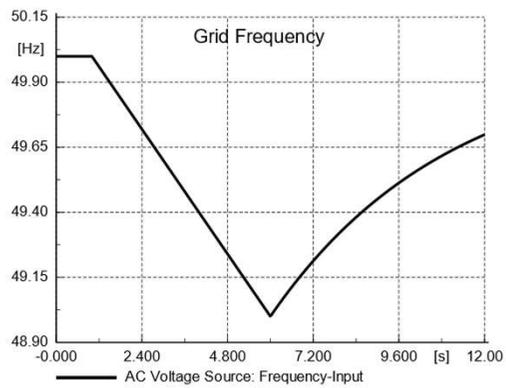
PSS poor performance causes



- Very large speed gain
- No washout filter on speed signal
- Long overall washout filter time constant
- Likely frequency disturbance not considered at time of design

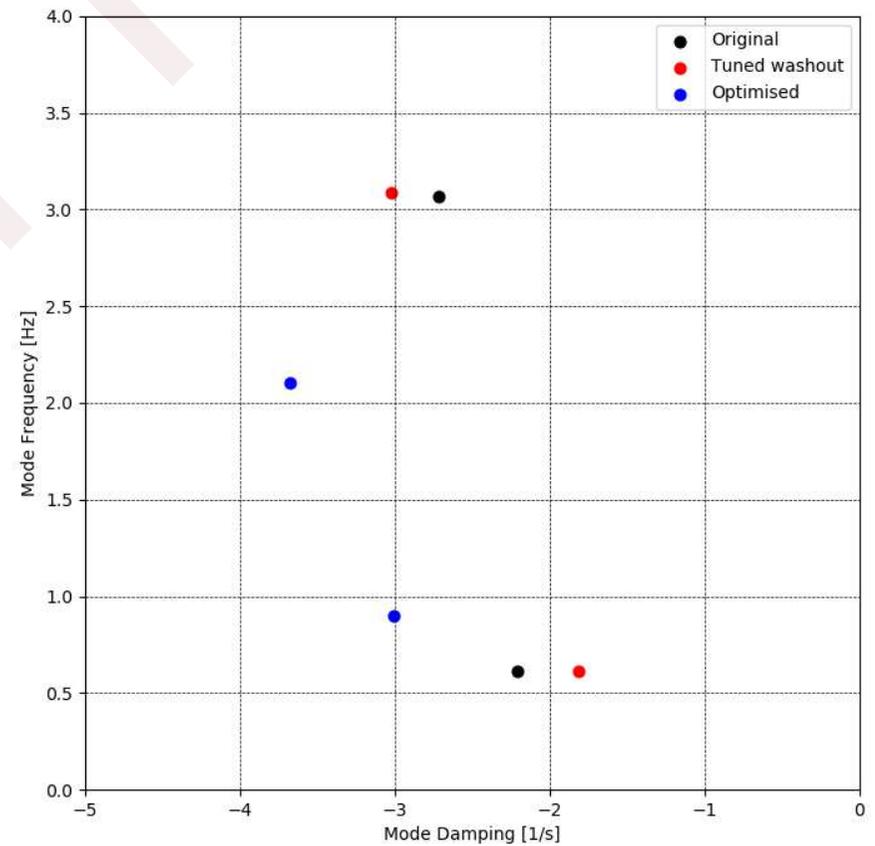
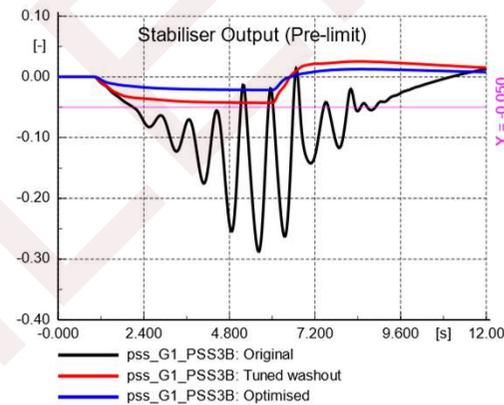
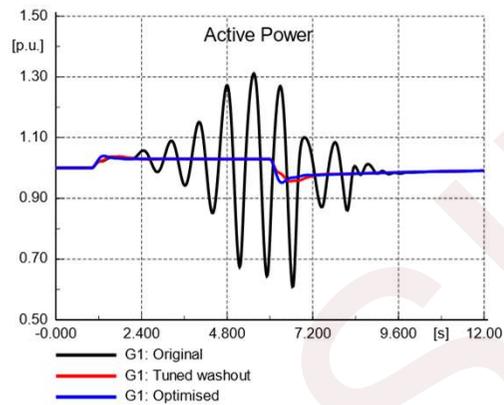
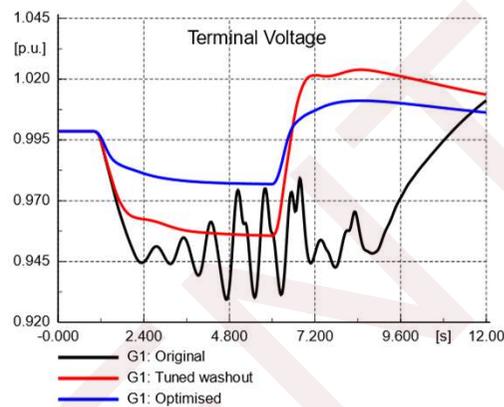
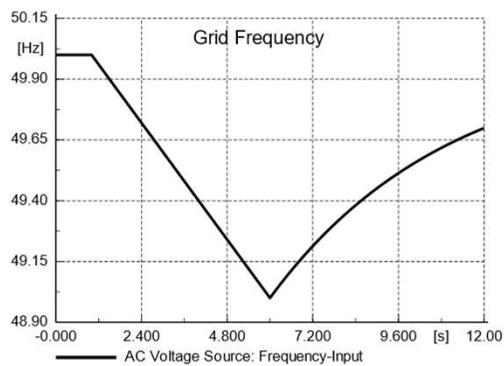
PSS solution 1

- Tune washout filter



PSS solution 2

- Tune washout filter and PSS gains



Case study: VRE impact on stability

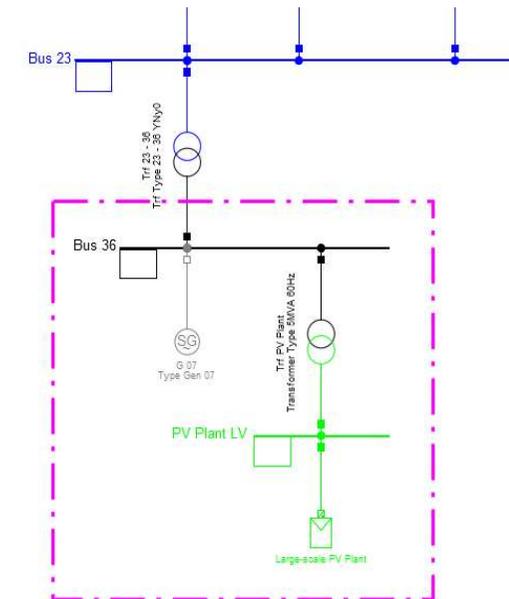
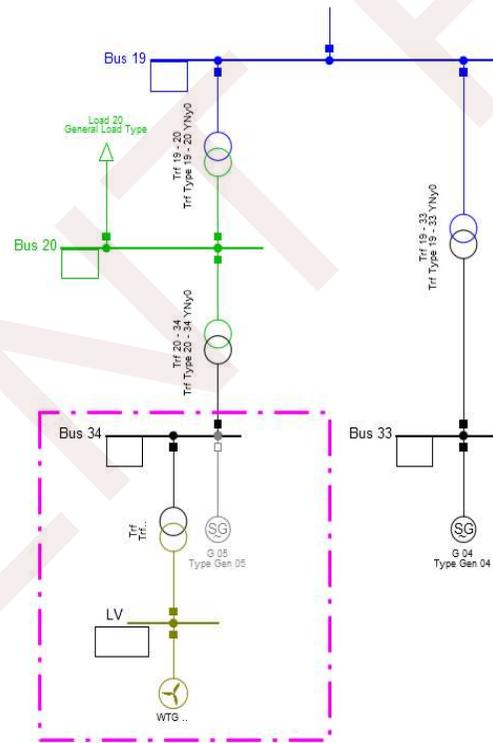
- Penetration of VRE is expected to have an impact because:
 - Reduction in system inertia
 - Retirement of coal-fired generators – Hazelwood, Liddell?, ...
 - Reduction in system strength
 - Increase in inverter-based generation
 - Inverter-based resources exacerbate system strength issues
 - Faster controller action in the grid
 - Need to comply with the NER which has high performance-based metrics
 - In a weak grid (low system strength, low inertia) we see instability associated with fast acting controls and voltage instability (e.g. West Murray Zone)

Case study: VRE impact on stability

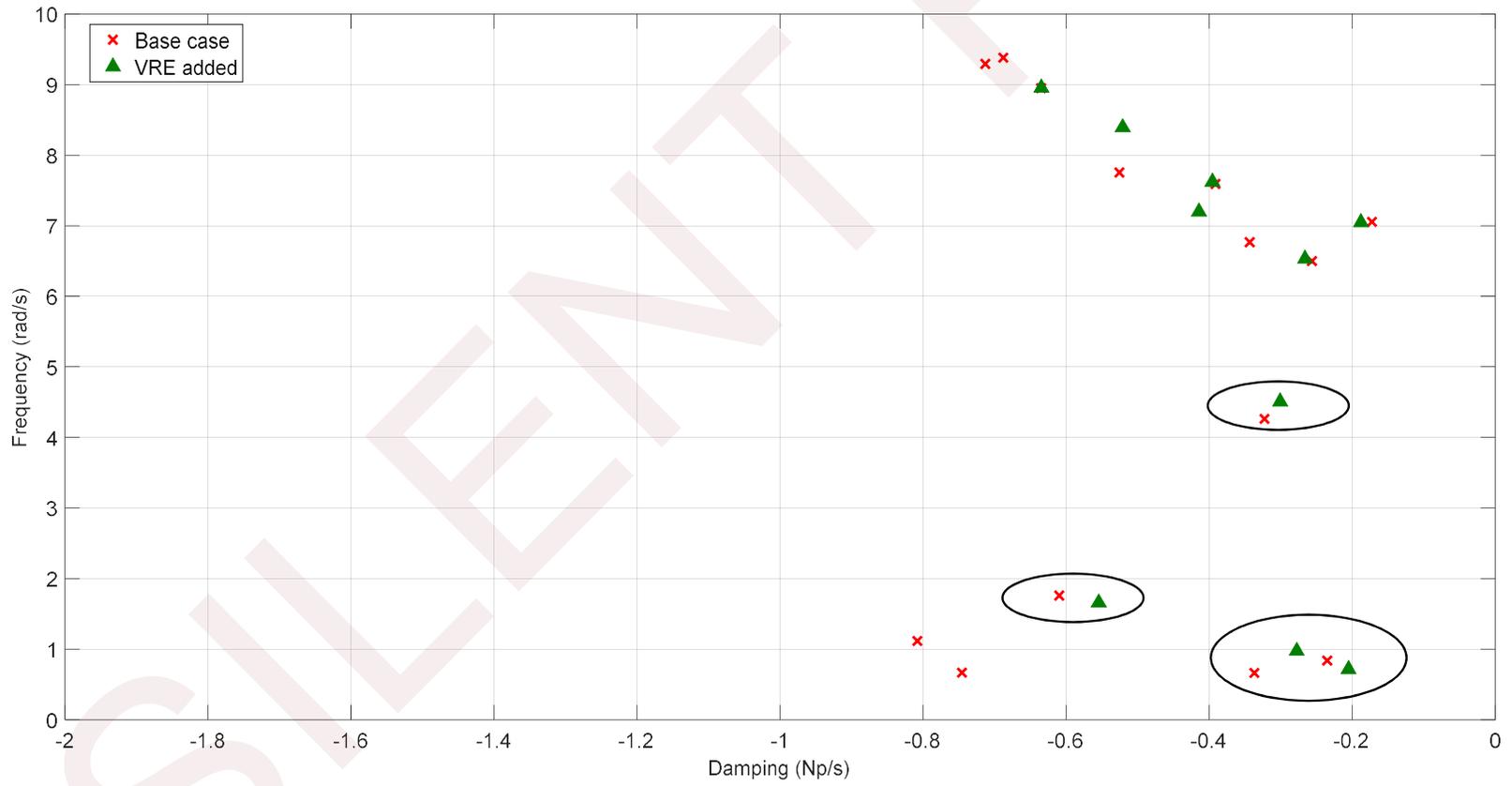
- Case study: 39 bus "New England" system
- Total generation dispatched of 6.1 GW (100% conventional)
- Available system inertia of $\sim 4.58s$
- Single largest generator excluding the interconnection to rest of USA is 1,000 MVA

Test system – VRE added

- Retired generators G05 (300MVA) and G07 (700MVA)
- Replaced with a WTG (660 MVA) and PV plant (550 MVA) – standard dynamic models also included
- System inertia reduces from 4.58s to 4.29s

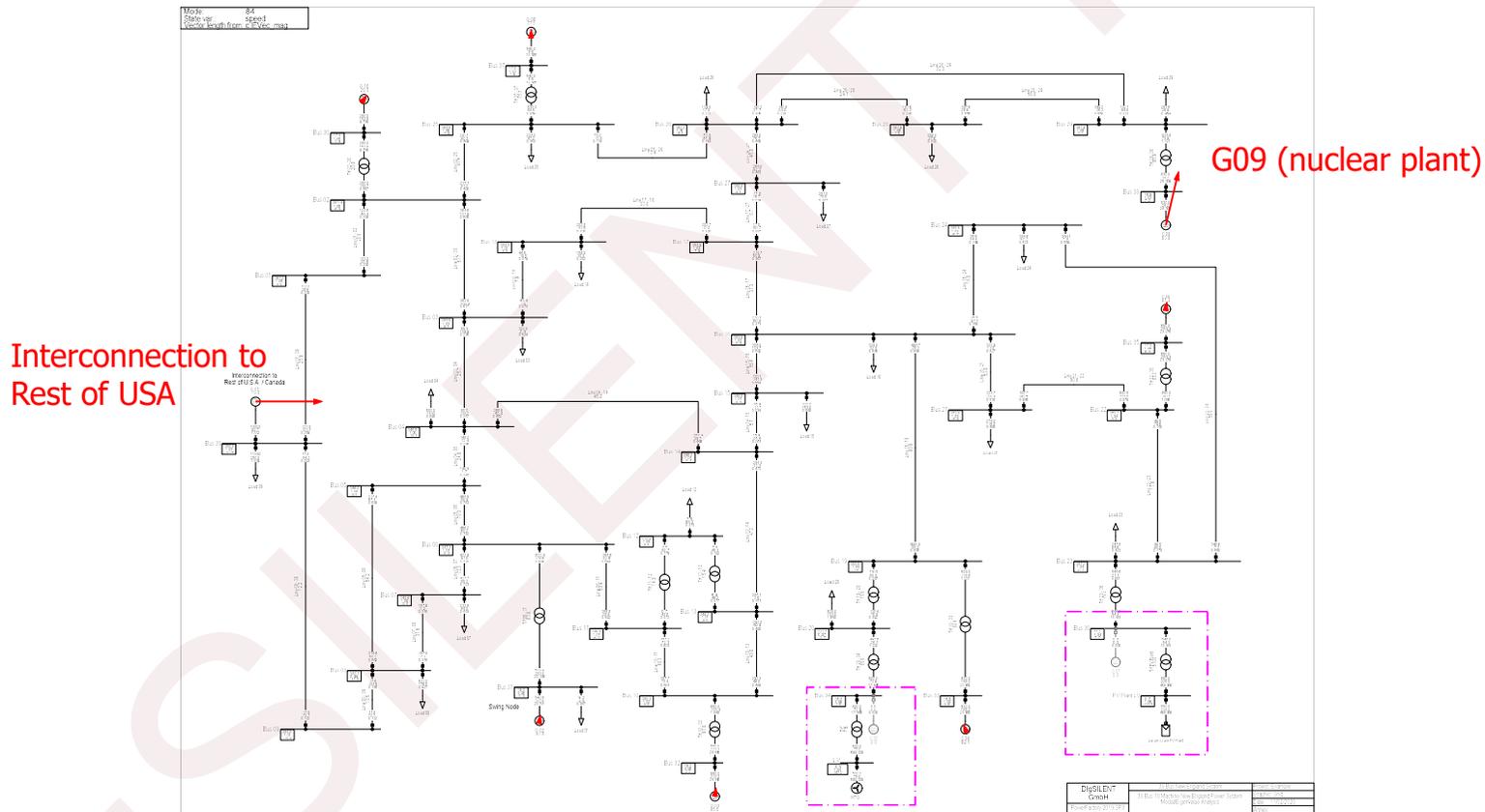


Test system – VRE added

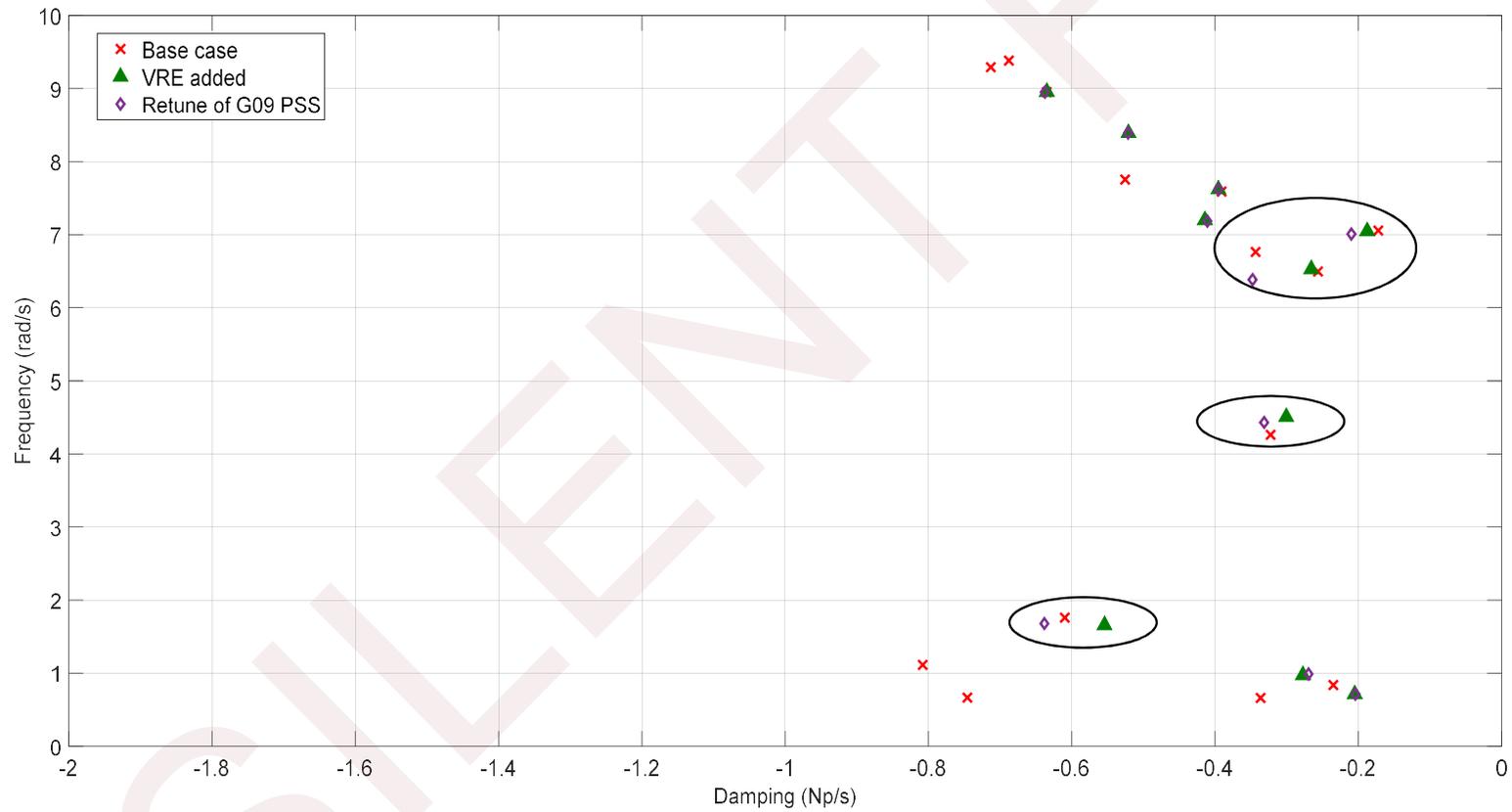


Test system – study of mode 84

- One mode selected: $-0.64 + j1.68$ (frequency of 0.27 Hz)



Test system – retune of G09 PSS



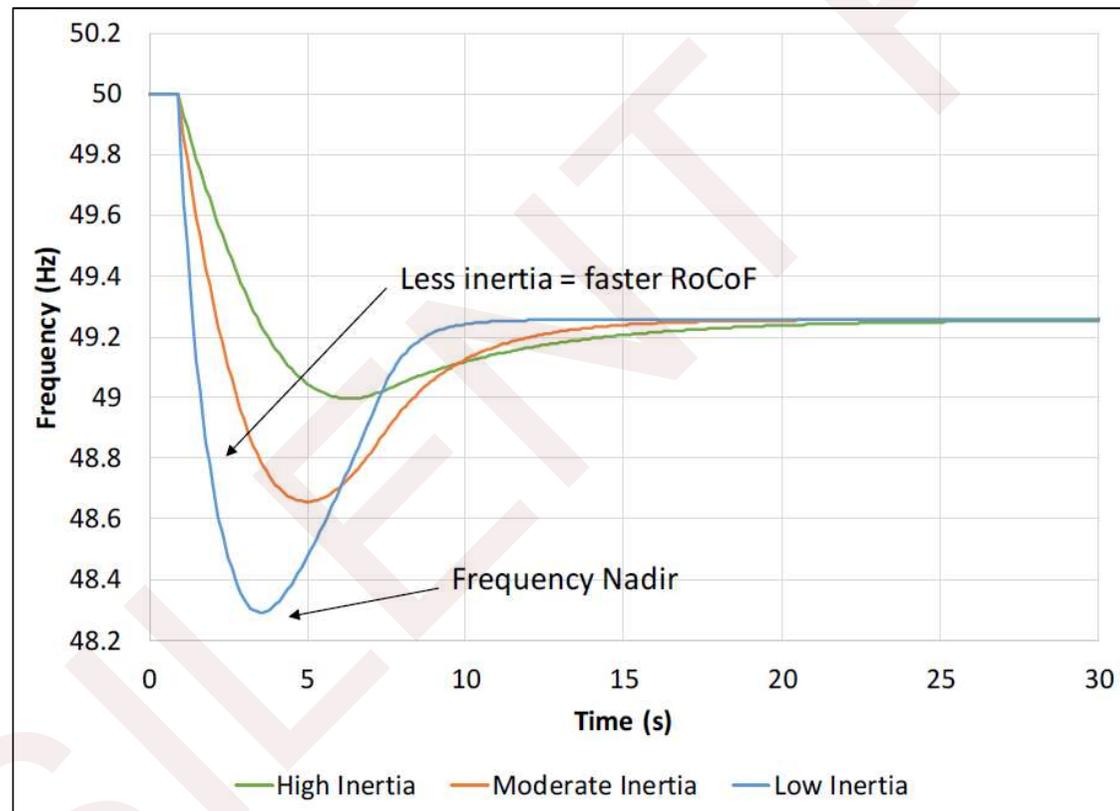
Case study: Reduction in inertia

- The aggregated system inertia can be calculated in MW.s

$$H_{TOT} = \frac{\Sigma H_i S_i}{S_{SYS}}$$

- Smaller values of H lead to higher RoCoF which causes rapid changes in system frequency and less stable behaviour
 - Load shedding
 - Cascade tripping
 - System collapse

Case study: Reduction in inertia



Case study: Reduction in inertia

- **Using “New England” test case**
- Effect of VRE on transient stability is analysed by looking at a distant fault on Line 02-03
- Using base-case (no VRE, higher system inertia), CFCT for a 3ph SC on Line 02-03 is found to be **240ms**
- With the addition of VRE and retirement of two generators, CFCT for same fault is found to be **200ms**
- Reduction in CFCT of 16%

Case study: Reduction in inertia

- Case study B:
- Existing Power Station with four gas turbines, upgrades turbines to light-weight aero-derivatives with lower inertia
- Aero-derivative turbines have much faster start-up times (start to P_{MAX} in 5mins), and are able to respond to market demands quicker than heavier duty OCGT
- Disadvantage is the reduction in turbine inertia will have an impact on the Station to ride through disturbances (**compliance with GPS**)
- Study is performed analysing CFCT for a 3ph fault at the POC in a reduced network simulation

Impact on transient stability – CFCT in SMIB

Units in service	Comments	Inertia (s)	Total inertia	CCT
1	Unit 1 upgraded, dispatched in isolation	1.9	1.9	0.2
1	Unit 1 pre-upgrade, dispatched in isolation	2.6	2.6	0.22
2	Unit 1 upgraded, Unit 2 pre-upgrade	Unit 1 = 1.9 Unit 2 = 2.6	2.25	0.1375
2	Unit 1 and Unit 2 upgraded	Unit 1 = 1.9 Unit 2 = 1.9	1.9	0.135
3	Unit 1 and 2 upgraded, Unit 3 pre-upgrade	Unit 1 = 1.9 Unit 2 = 1.9 Unit 3 = 2.6	2.133	0.1175
3	All upgraded	Unit 1 = 1.9 Unit 2 = 1.9 Unit 3 = 1.9	1.9	0.1125
4	Unit 1-3 Upgraded, Unit 4 pre-upgrade	Unit 1 = 1.9 Unit 2 = 1.9 Unit 3 = 1.9 Unit 4 = 2.6	2.075	0.112
4	All upgraded	Unit 1-4 = 1.925	1.9	0.105

Findings

Case	Findings	Recommendations
Legacy stabilisers on existing conventional generators	<p>Set and forget!</p> <p>Design likely not appropriate for current network conditions</p>	<p>Do now: Re-tune stabilisers for optimum performance (5.3.9 process?)</p> <p>Wait and do: Wait as legacy systems are phased out during AVR upgrades</p>
Impact of VRE on small signal stability	<p>Shift in modes (not all are bad)</p> <p>Some inter-area modes may be found to be less damped</p>	<p>Co-ordinated study and setting of controllers (and PSS's) to improved damping</p> <p>As above (re-tune PSS's)</p>
Reduction of system inertia	<p>High RoCoF</p> <p>Reduction in CFCT</p>	<p>Synchronous condensers</p> <p>Synthetic inertia</p> <p>Inertia response as an ancillary service</p> <p>Braking resistor</p>

Final remarks

- Most of our conventional generators are ageing assets that need to be managed and considered as today's grid is changing
- We need to consider the limits of legacy systems
- Performance of conventional generators could be optimised through a coordinated approach as more VRE comes online



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