Oscillation Source Location by Mode Phase

IEEE PES GM Tutorial, Boston

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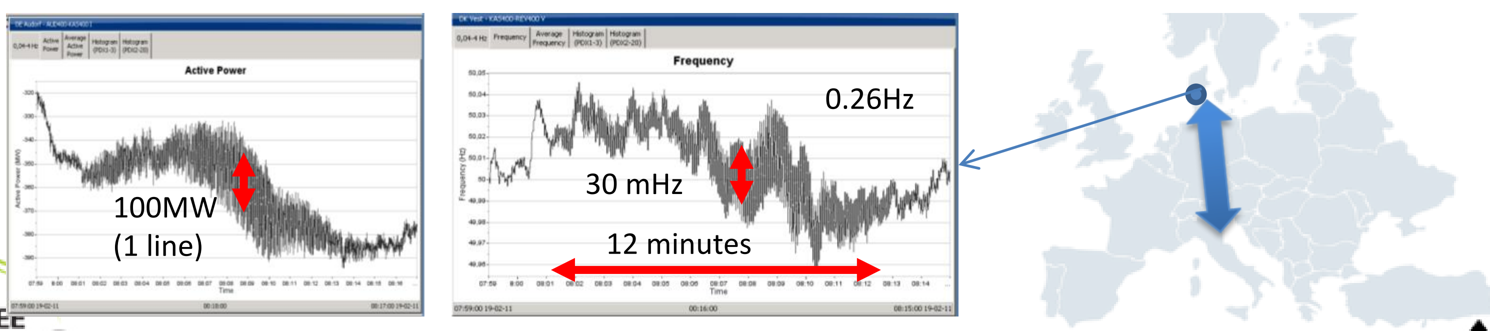
Imagination at work

Introduction

Need for Source Location in Managing Oscillations

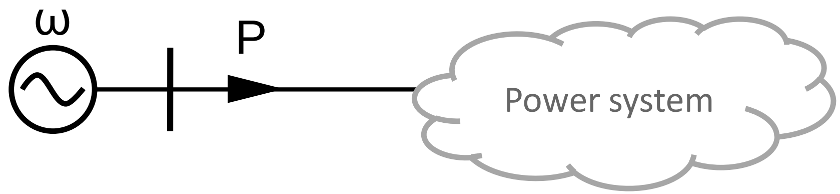
- Oscillation Identification long established (since 1998), revealing unforeseen issues
- Oscillation behaviour can be complex
  - Many plants, loads, controllers participating over wide area
  - Issues not replicated in models e.g. interaction/resonance, plant malfunction, forcing
- **Decisions on actions** (real-time or planning) require information to identify sources
  - Applicable to interconnection (is source in my area?)
  - “Largest amplitude” an unreliable indicator, and observability incomplete (especially currents)

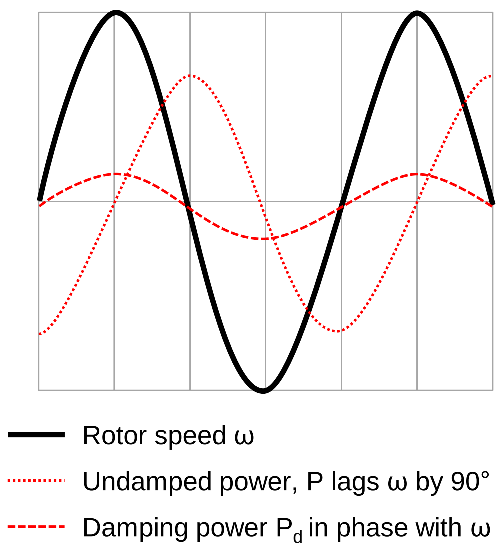
New method yields **Source Identification** using **Sparse Voltage Bus Measurements**

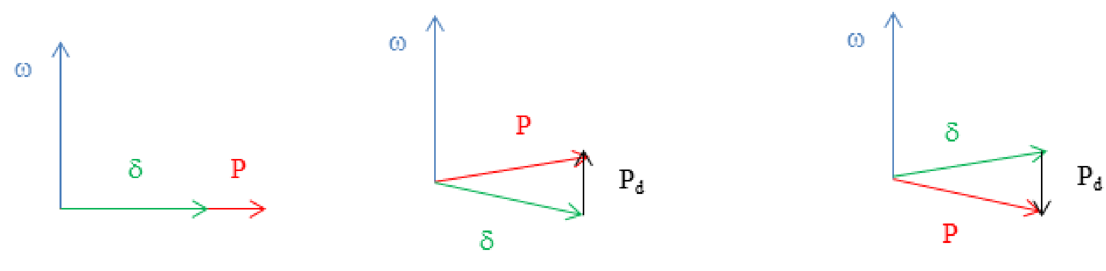


Oscillation Source Location Approach

Phase Relations (1 machine)



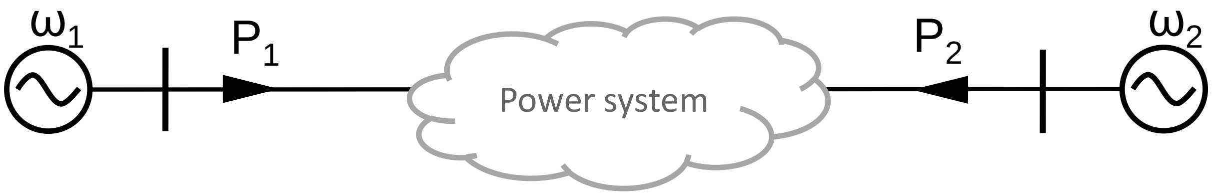


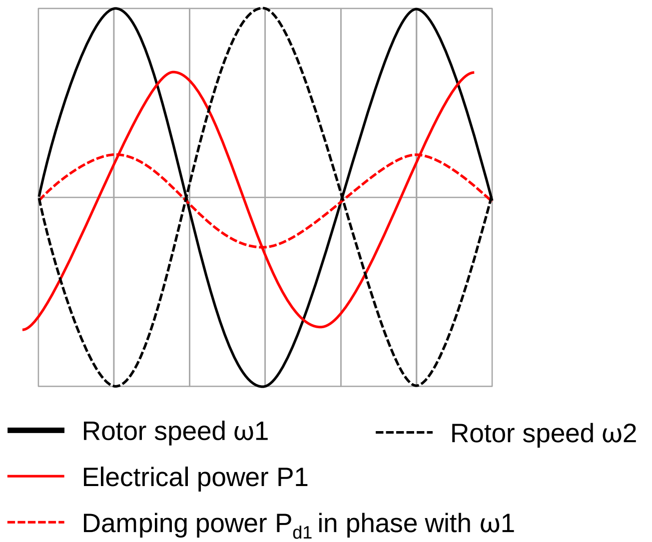


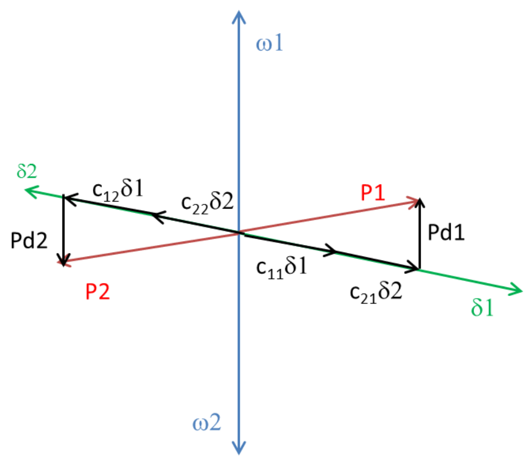
(a) Undamped (b) Positive Damping (c) Negative Damping

- P and δ lag ω by about 90°, determined by mode damping
  E.g. damping ratio 20%, angle lags 90°+12° and power lag speed by 90°-12°
- Power in phase with speed produces damping

Phase Relations (2-Machine)

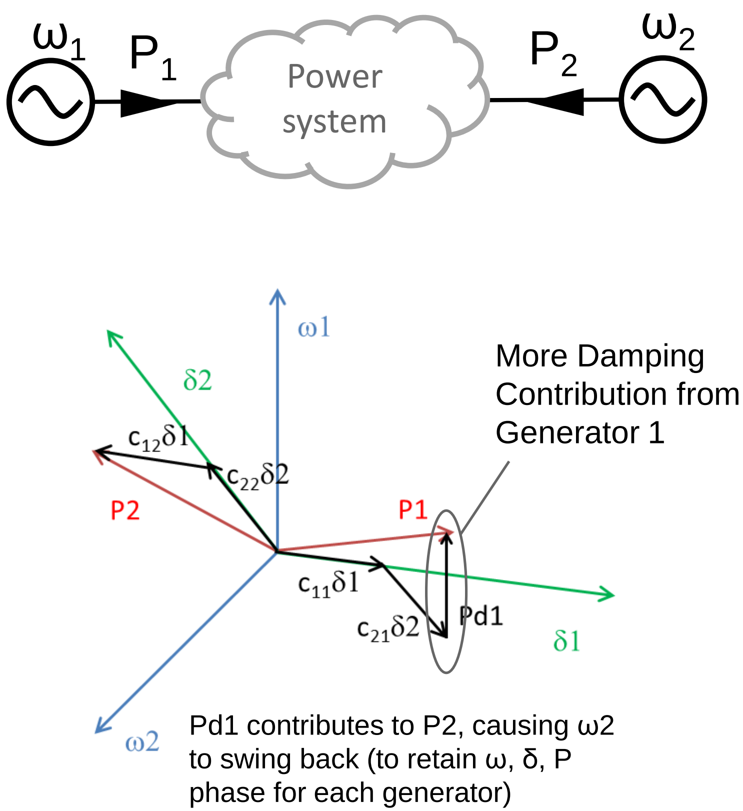


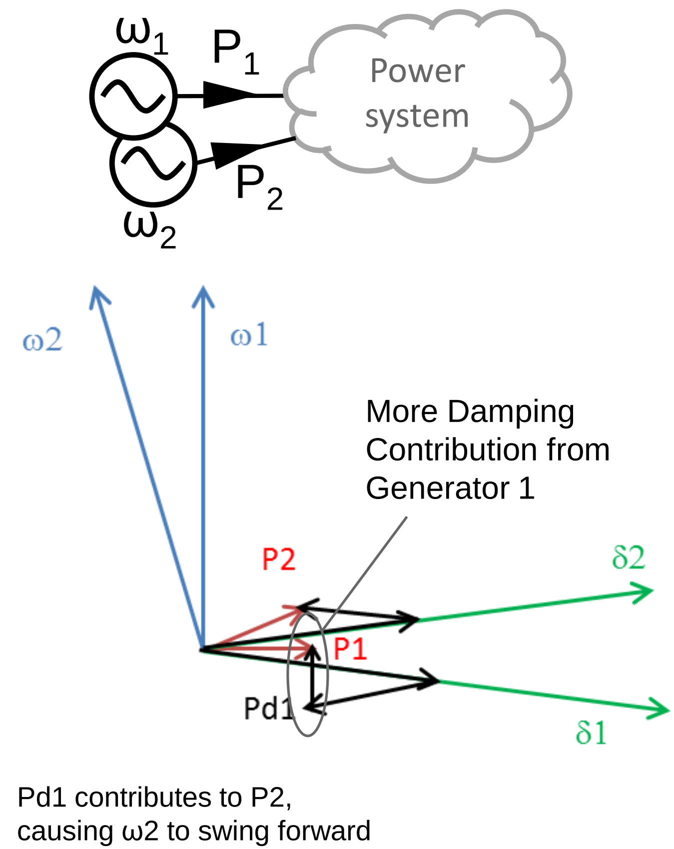




- Rotor speeds 180° out of phase
- Equal damping contributions from each generator, influencing the local and remote generators

Phase Relations (asymmetric)





Lagging group (<180°) contributes more damping
Leading group is "source" of problem

Lagging generator contributes more damping
Leading generator is "source" of problem

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Total Damping Contribution

Unit i damping contribution

θ_i - θ_j positive where unit i is poorly damped in comparison to j

a_i damped amplitude at i

$$D_i = \sum_{j=1}^{n} c_{ij} * a_i * \mathrm{Sin}(\theta_i - \theta_j)$$

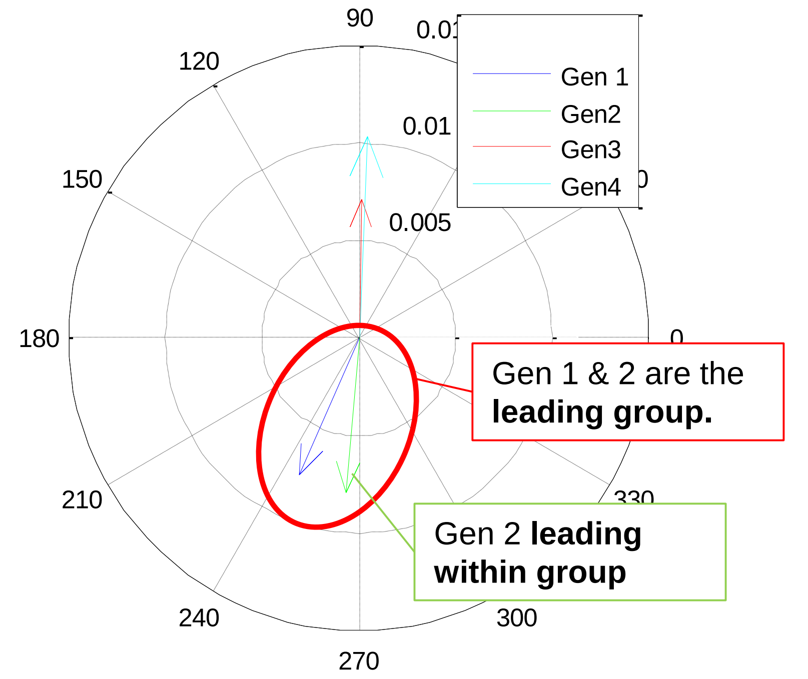
c_{ij} Inversely proportional to impedance between units i and j thus small if units are distant

Simplifying assumptions can be made for most cases – where the mode involves either one or two main groups, avoiding need for model.

Identifying Sources of Oscillations

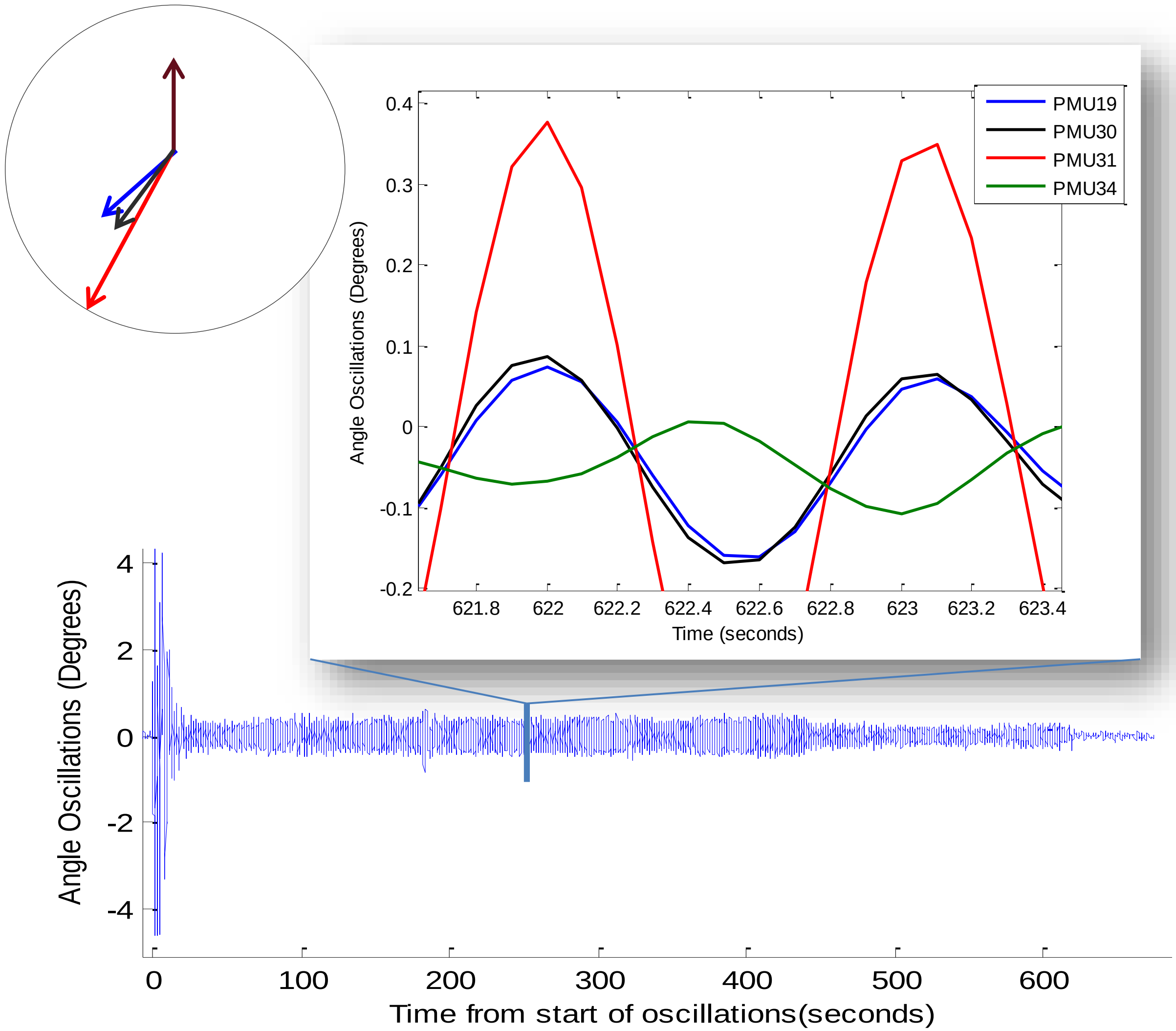
Example

- The "source" is the location with lowest damping contribution (possibly negative).
- To find the source of an oscillation:
  1. Divide into opposing groups. The group leading by less than 180° is the group containing the source.
  2. Find the most leading location within the leading group.



Gen 2 is the Source

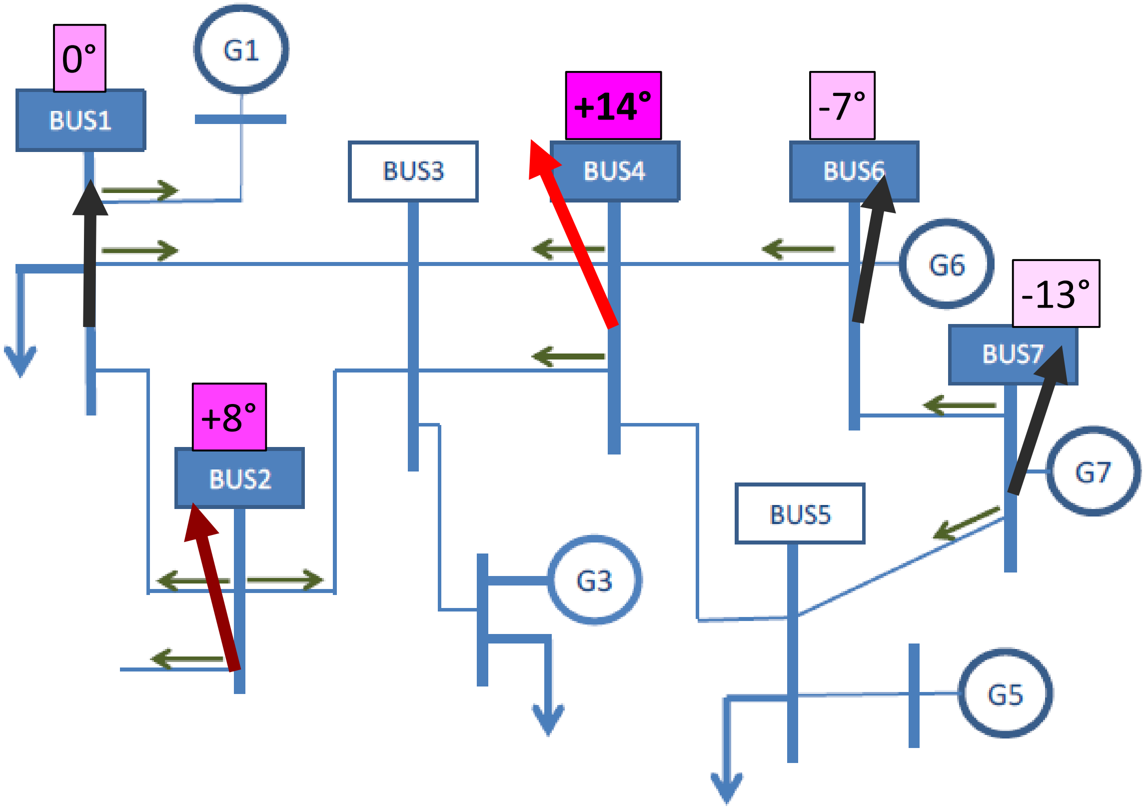
Real System Case from ISO-NE



Undamped 0.9 Hz oscillations after disturbance

- Amplitude and Phase differences in time domain signals.
- Group 19,30,31 leads 34 by <180°
  → **source group is PMUs 19, 30, 31**
- Within source group, 31 leads 30 & 19
  PMU31 is source

NASPI Oscillation Case 2

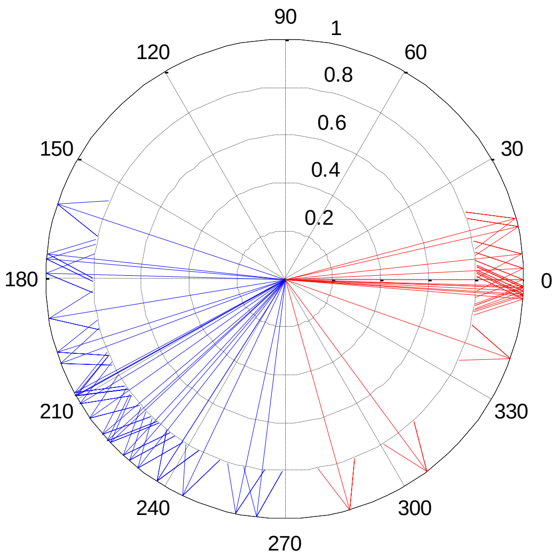


Undamped 1.25 Hz oscillations

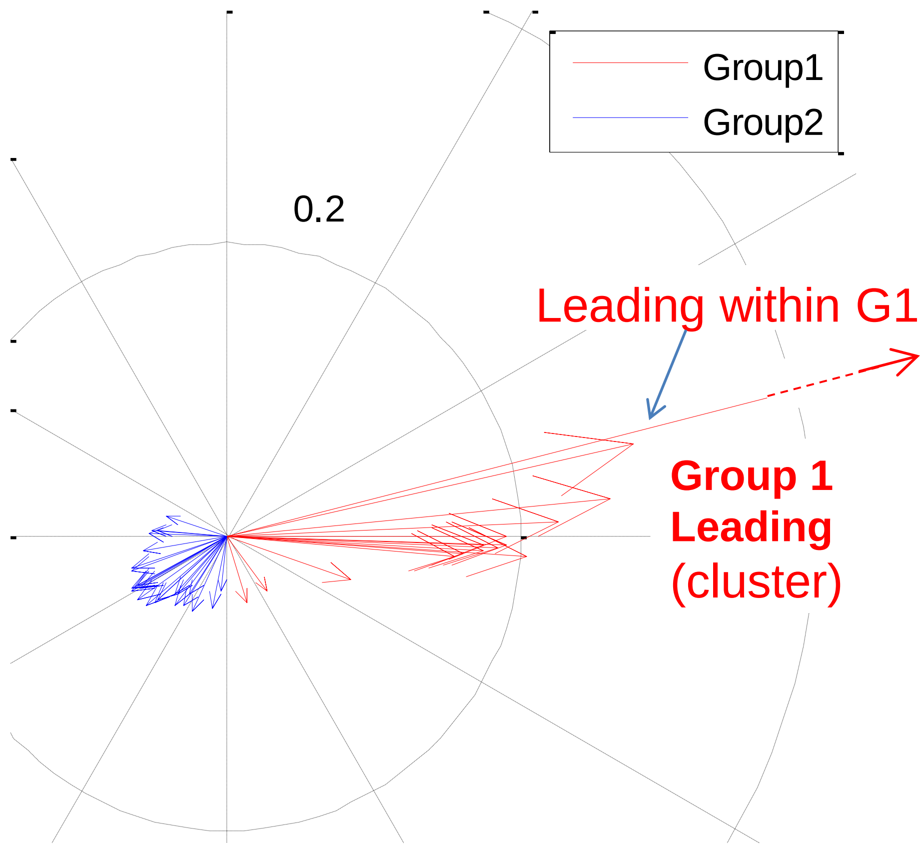
- BUS4 is closest to source; BUS2 second; others lag (actual source not measured)
- **Correctly indicates G3** (BUS1&6 show less contribution at G1&6. G5 possible but only if electrically close to BUS4)
- **Identified with sparse measurements, no power**

PMU Location	Source Location Measure
Bus 4	0.24
Bus 2	0.13
Bus 1	-0.01
Bus 6	-0.13
Bus 7	-0.23

ISO-NE case, all 39 measurements

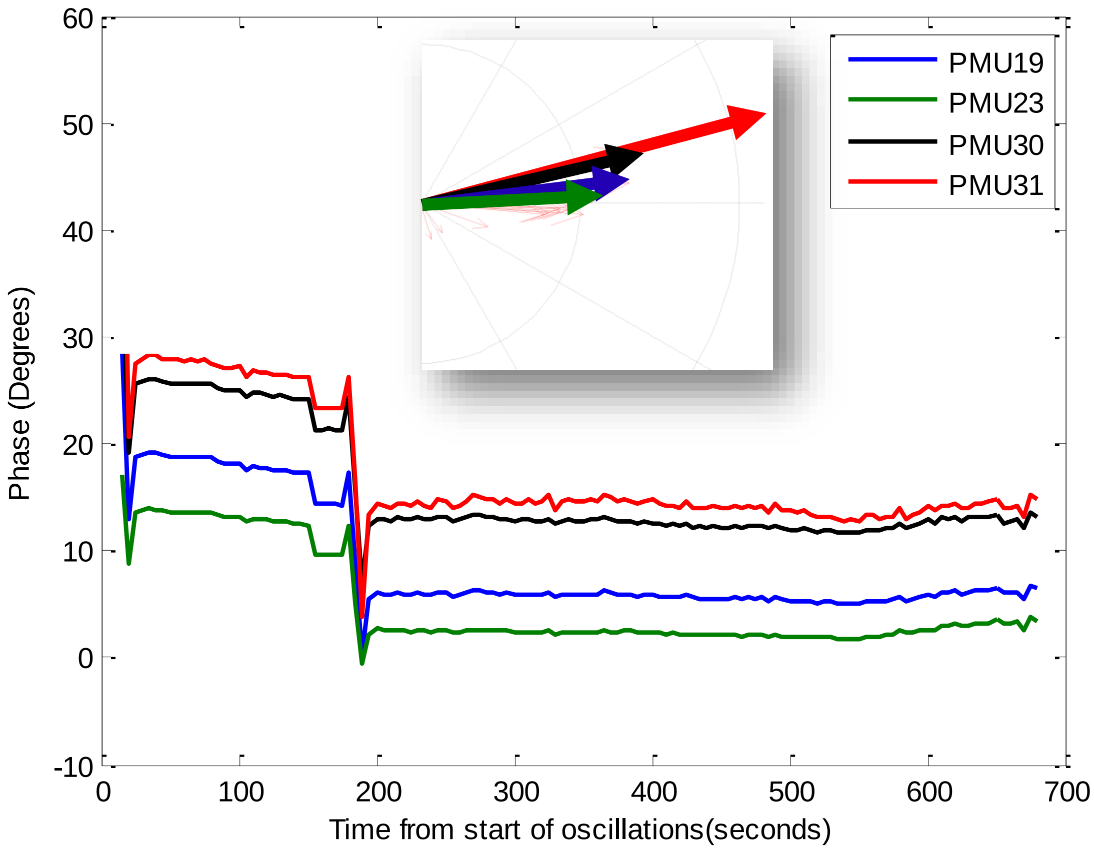


Angle Only



Angle & Magnitude

Most Leading Within Group 1

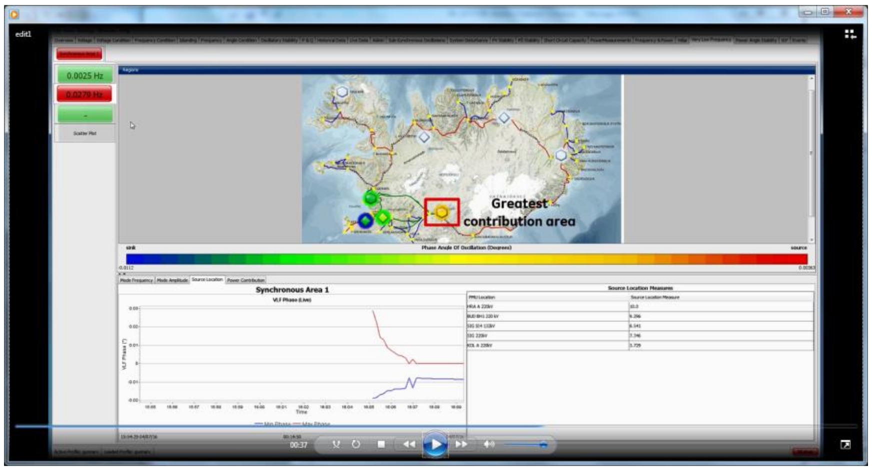


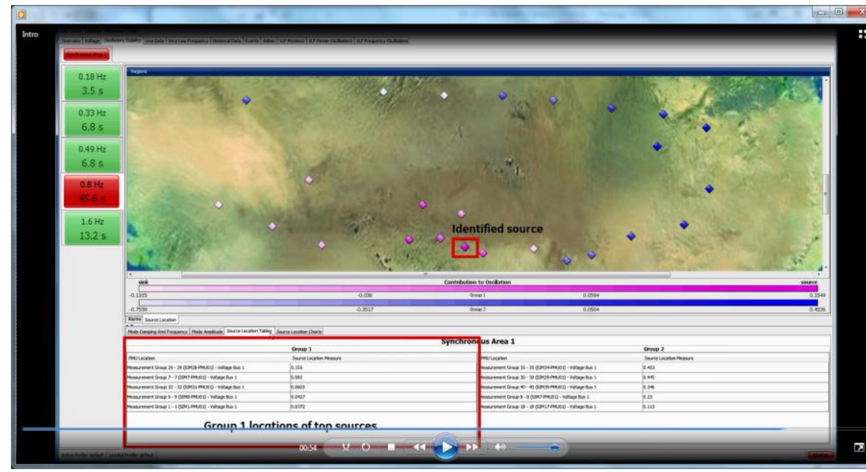
- Within Group 1, PMU31 is leading → **small or negative damping near PMU31.**
- If PMU31 was not available, PMU30 would be indicated, which is near PMU31, but much lower mode amplitude. Correct conclusion would be reached without PMU31.

Correct Conclusion to Nearest PMU, even without Large Amplitude

Practical Application in Source Location Tool

Video Demonstrations





VLF Common Mode

LF Inter-Area Mode

Application to Large Interconnections

Concern

- **Are there significant oscillations in interconnection?**
- **Is my system involved?**
- **Can the oscillation be controlled within my area?**
- **What measures can I take?**
  - Operationally
  - Planning & control design

Solution

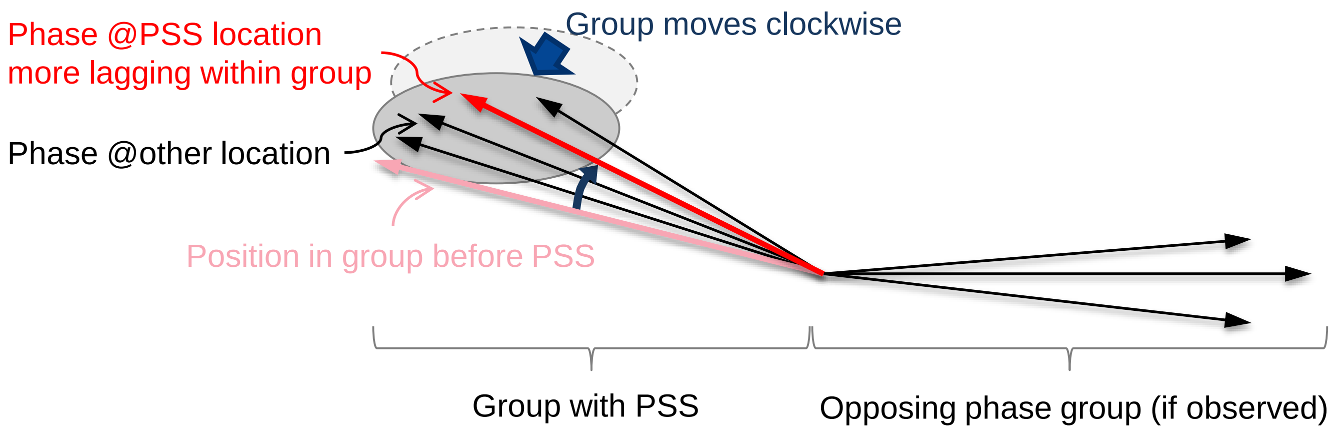
- Alarm on unusually large or poorly damped oscillations
- Check high level geographic interconnection source location view
- Compare contributions inside & outside system – action if source(s) within system
- Identify specific source plant(s) in detailed measurements
  - Change V/VAR dispatch, P dispatch if necessary. Inform plant.
  - Improve PSS, SVC-POD control design **at key plant(s).** Confirm wide-area response after commissioning

Approach can be applied to a large interconnection by sharing
a high-level sparse set of voltage phasor measurements

Application to PSS Tuning

Evaluating PSS Performance in System

Mode phase change due to enabling a PSS with positive damping contribution

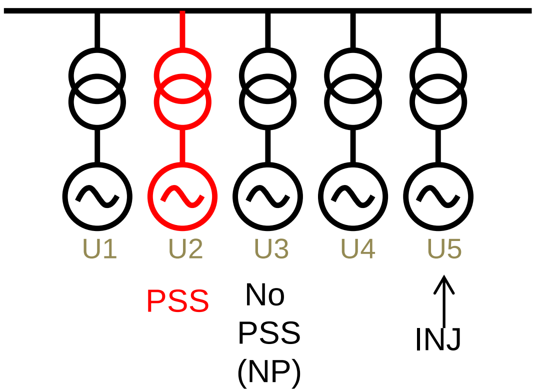


Good performance of PSS shown by:

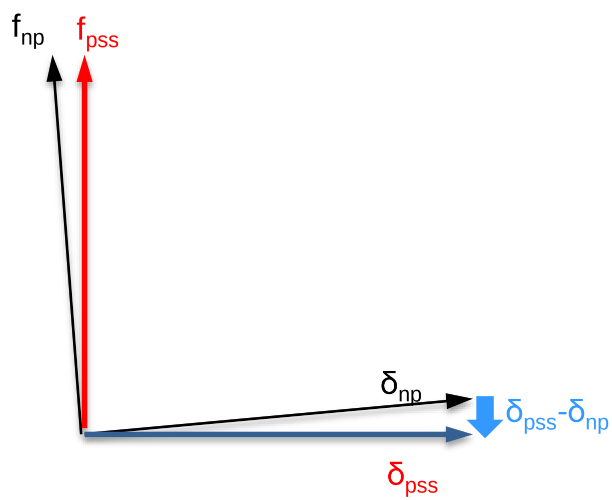
1. Mode phase of PSS generator becomes more lagging relative to rest of group
2. Mode phase of group becomes more leading relative to opposing phase group (if observable)

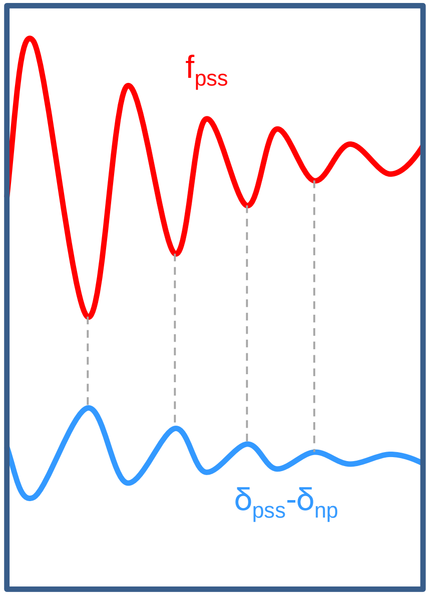
PSS Performance inter-machine

Angle and frequency at PSS machine should lag non-PSS. Although small, the effect should be observable as the direction of the oscillations in angle difference between machines.



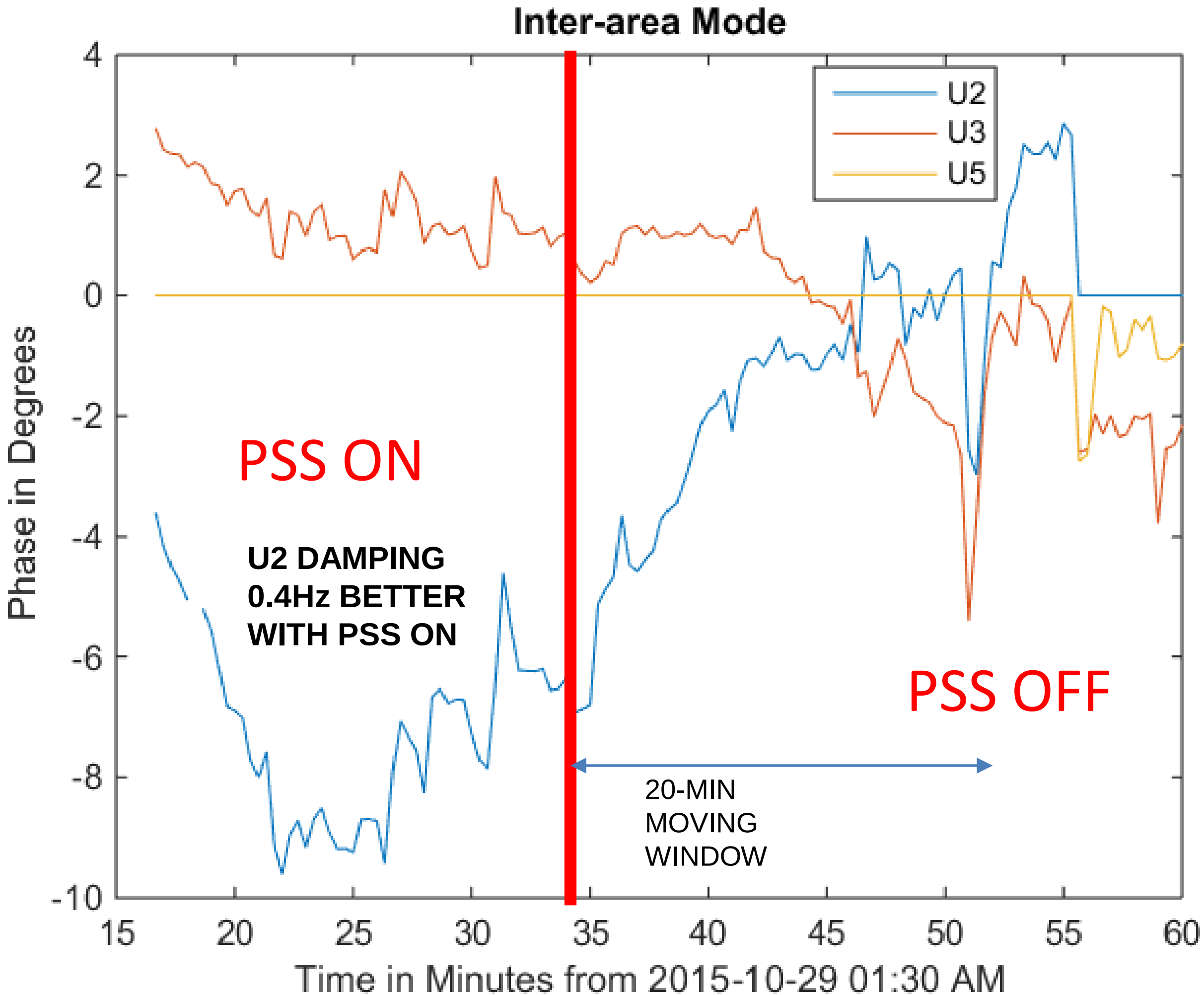
External disturbance, e.g. AVR step at generator not being compared





Good performance of PSS shown by $\boldsymbol{\delta_{pss}-\delta_{np}}$ i.e. δ_{pss} lagging δ_{np} is indication of good PSS performance at the machine.

PSS Commissioning for Interarea mode



WORSE DAMPING CONTRIBUTION

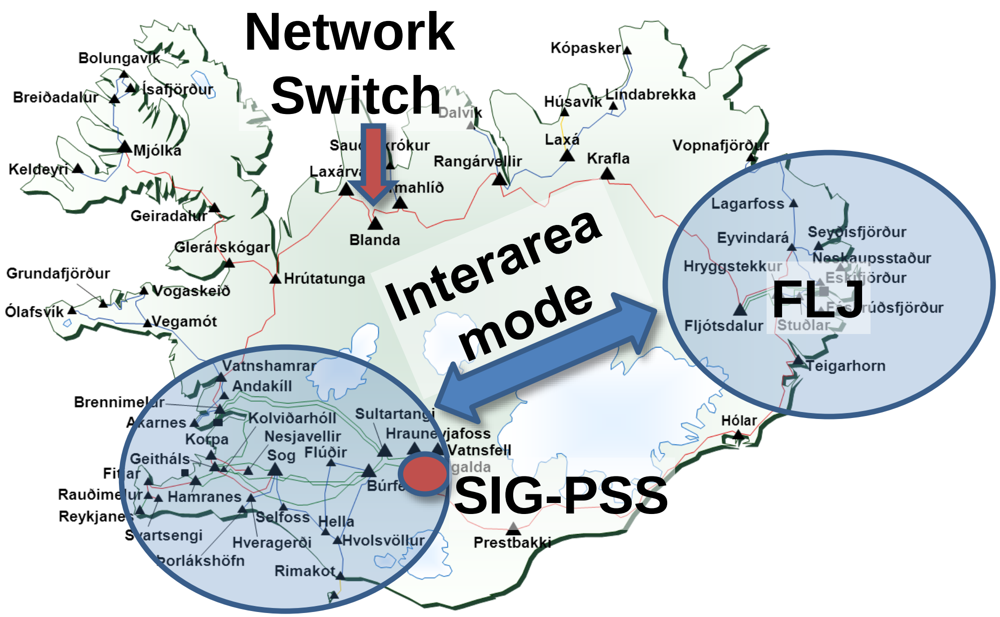
0.4Hz Mode: Machine phase (in P) significantly lags when PSS on, proving good damping.

Uses non-intrusive ambient noise.

BETTER DAMPING CONTRIBUTION

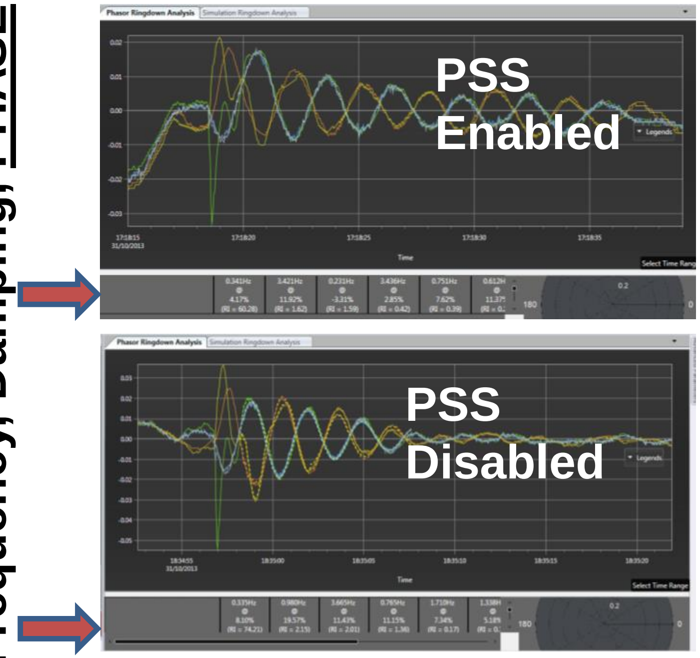
Real example from S. America, anonymised

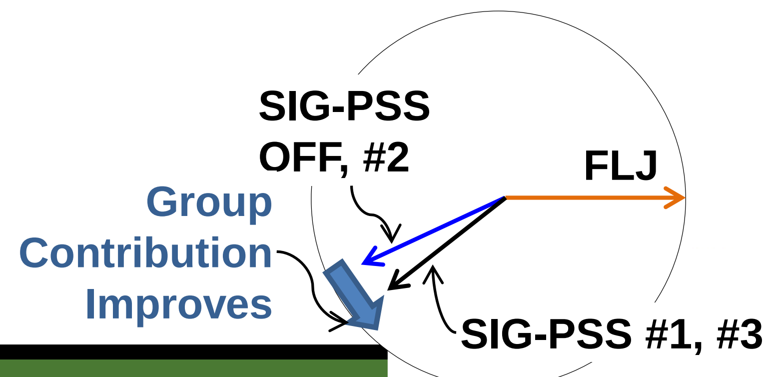
Contribution with different PSS settings



Switching Tests (opening)	Mode Frq	Damping	SIG-FLJ	Phase Change
PSS OFF	0.34	4.2%	-167.1	0
PSS #1 ON	0.33	6.8%	-156.2	10.9
PSS #2 ON	0.33	2.3%	-167.3	-0.2
PSS #3 ON	0.33	6.3%	-154.3	12.8

Frequency, Damping, PHASE





Conclusions

Conclusions

Advantages and Applications of Phase-based Source Location

- Novel measurement-based oscillation source location
  - Applies to voltage phasors, utilising high level overview and local detail
  - Applies to multiple modes and damped oscillations
  - Not dependent on currents or observing largest amplitude
- Applied to real system examples
  - Located key sources for VLF (e.g. 0.03Hz) and inter-area (e.g. 0.4Hz)
  - Process used for PSS tuning exercises
  - Live trial on GB system
- Using sparse measurements without power → practical
- Applicable from small systems to large interconnections
- Applicable in Real-Time or Analysis timeframe