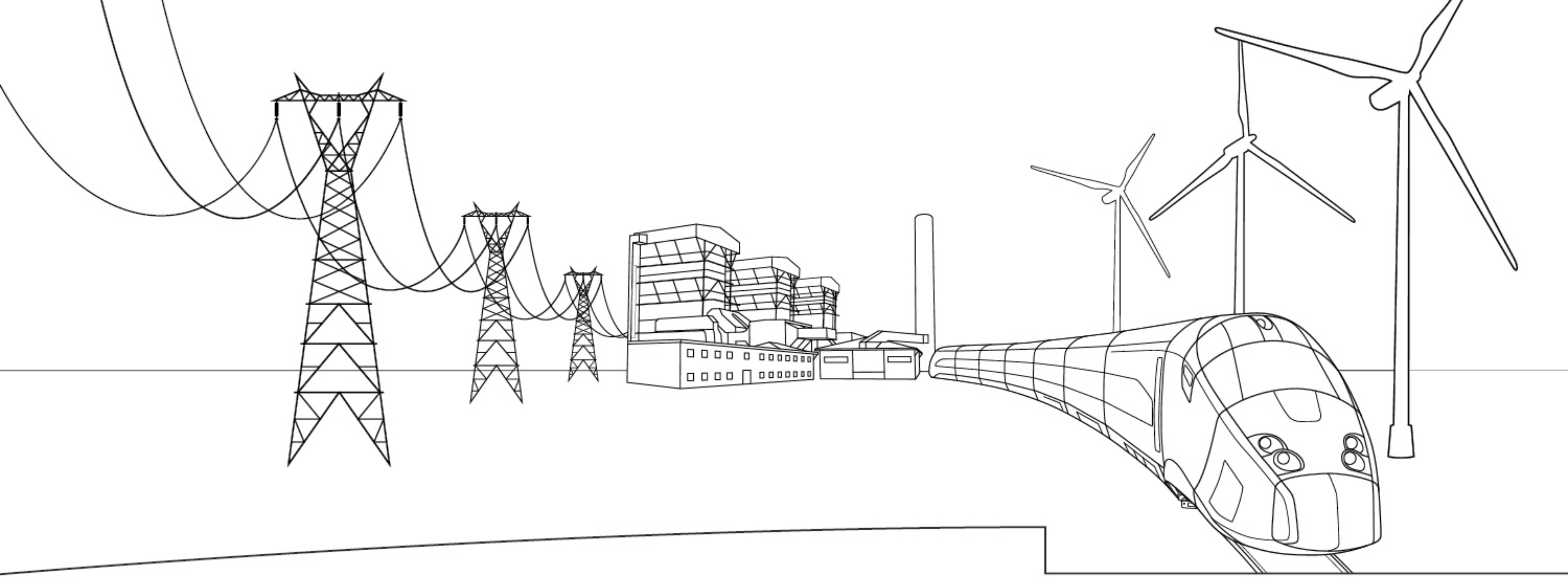

Identifying Sources of Oscillations Using Wide Area Measurements

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2014 Grid of the Future Symposium

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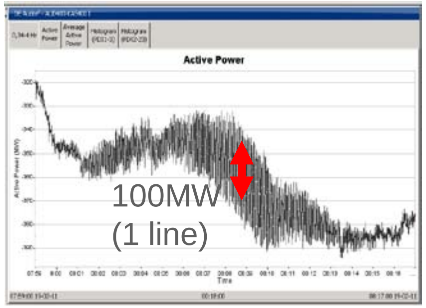
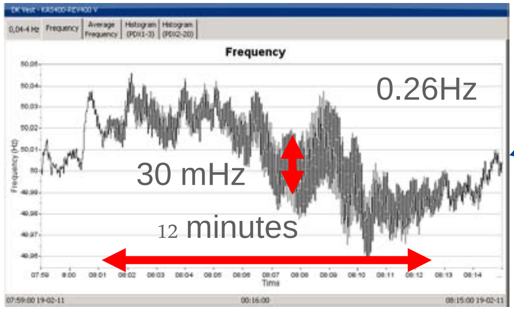
ALSTOM
Shaping the future

Need for Source Location in Managing Oscillations

- Oscillation Identification long established
  - Real-time control-room measures on known modes since 1998 (GB inter-area 0.5Hz)
  - Monitoring reveals previously unseen behaviour and risks
- 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
  - Assume incomplete observability (especially currents)

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





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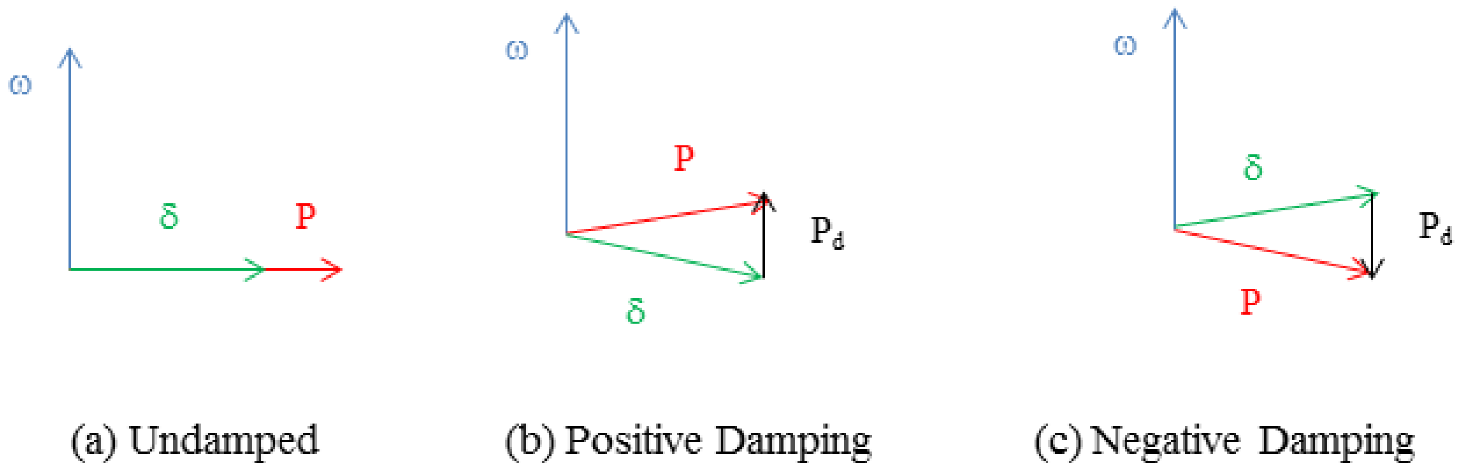
Oscillation Phase Relations for a Single Machine



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

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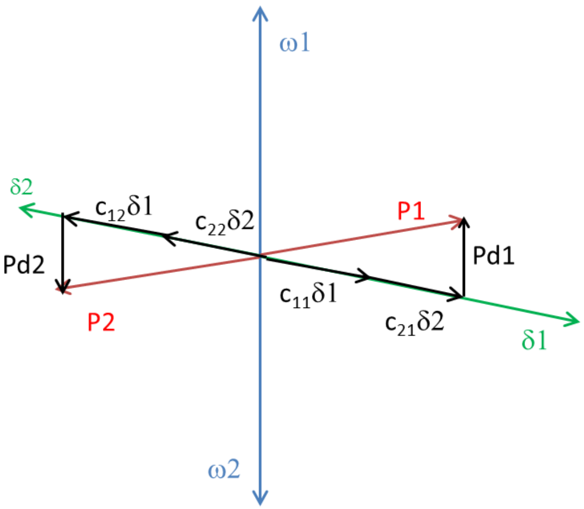
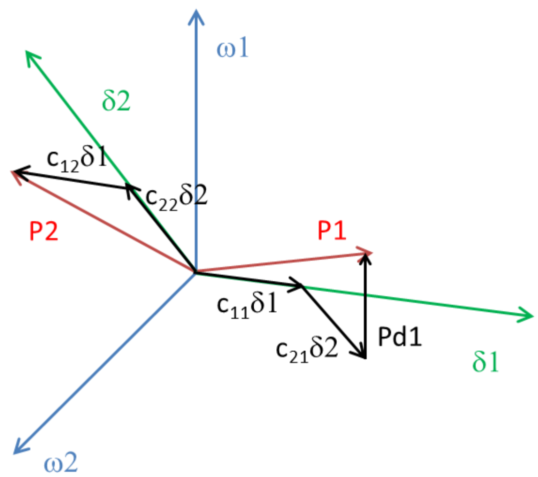
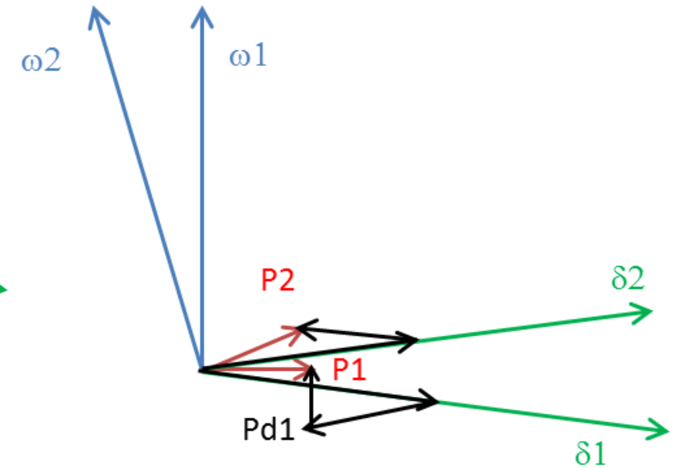
2-Machine Example



Equal Damping Contributions



More Damping Contribution from Generator 1



More Damping Contribution from Generator 1

Lagging generator contributes more damping than leading generator

Leading generator is “source”

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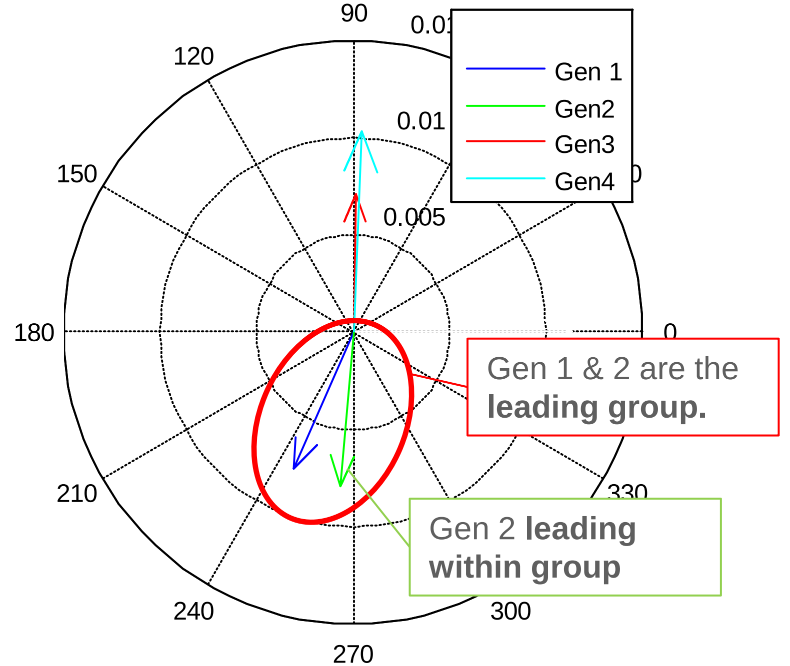
Identifying Sources of Oscillations

Example

- *Leading phase indicates less damping contribution.*
- *The "source" is the location with the 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

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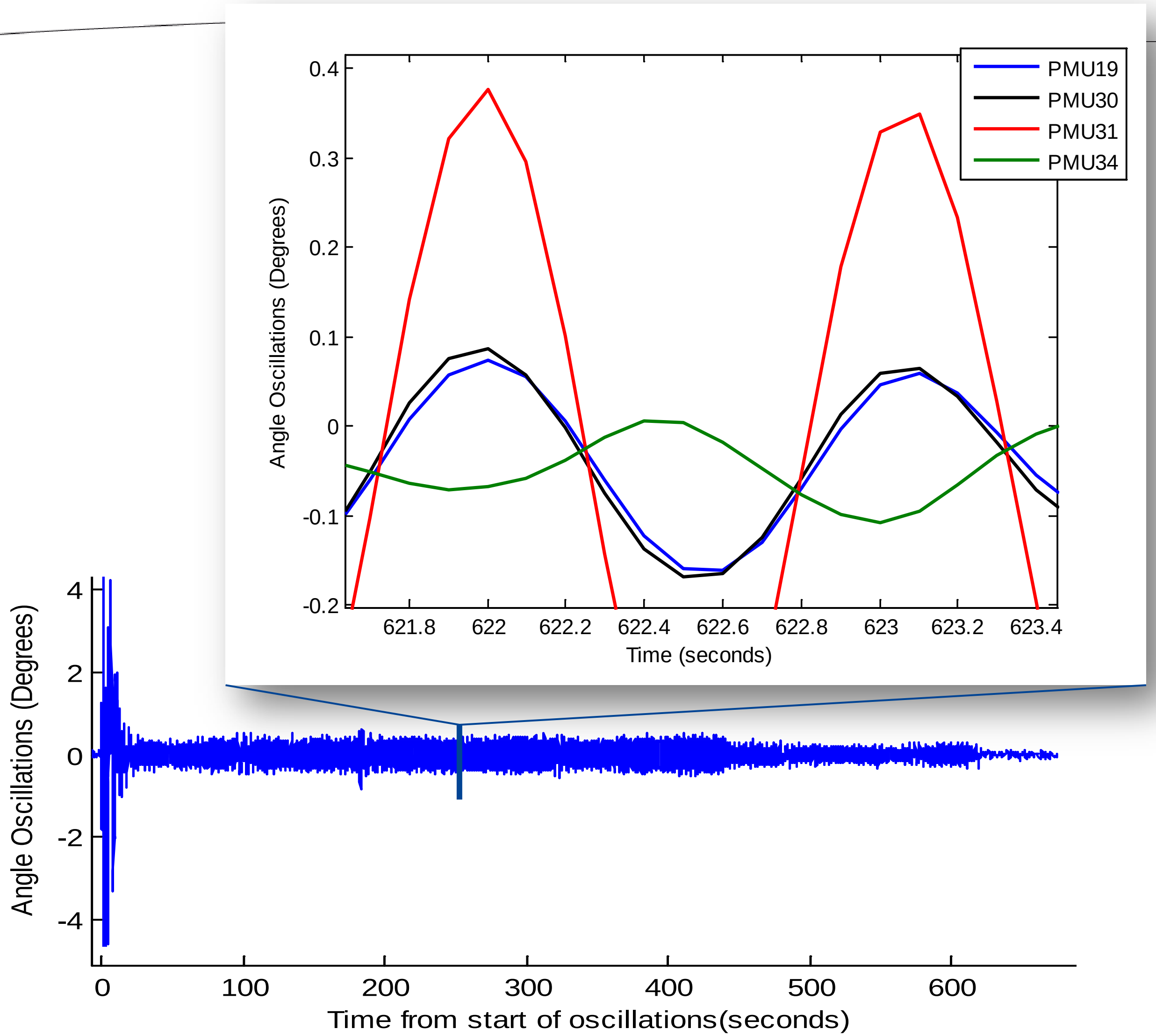
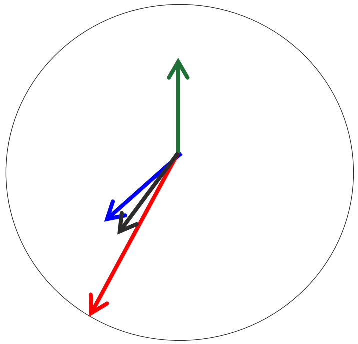
Real System Case from ISO-NE

Undamped 0.9 Hz oscillations after disturbance, 10 minutes.





- Amplitude and Phase differences in time domain signals.
- Group of PMUs 19,30,31 leads PMU 34 by less than 180° → **source group is PMUs 19, 30, 31**
- Within source group, phase PMU31→PMU30→PMU19. **PMU31 is source**

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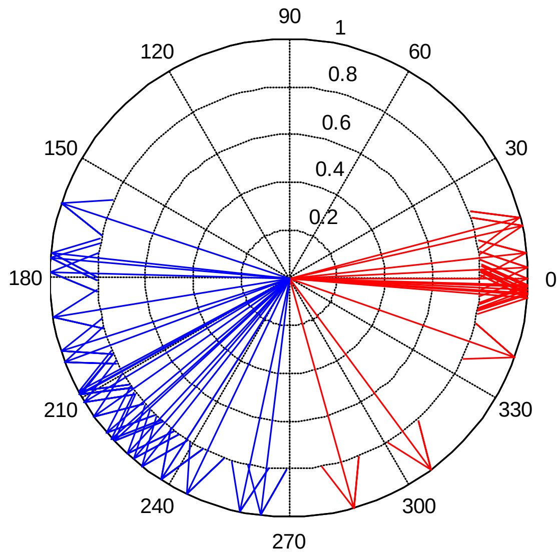
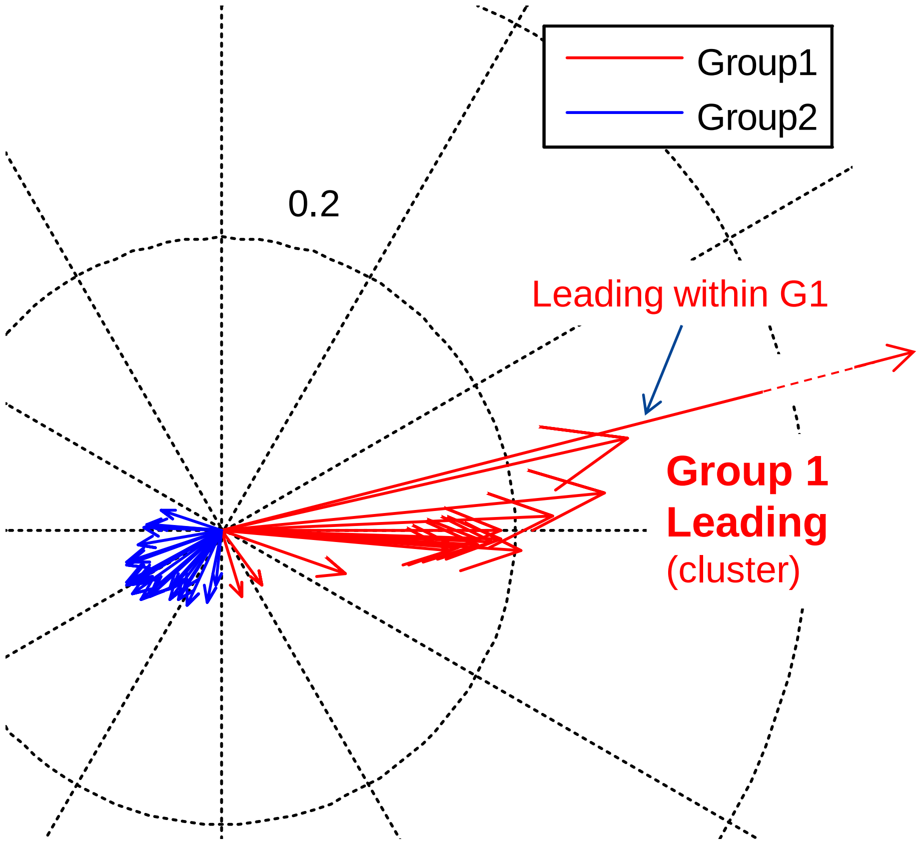
Mode Shape from all 39 measured locations.



Angle Only



Angle & Magnitude

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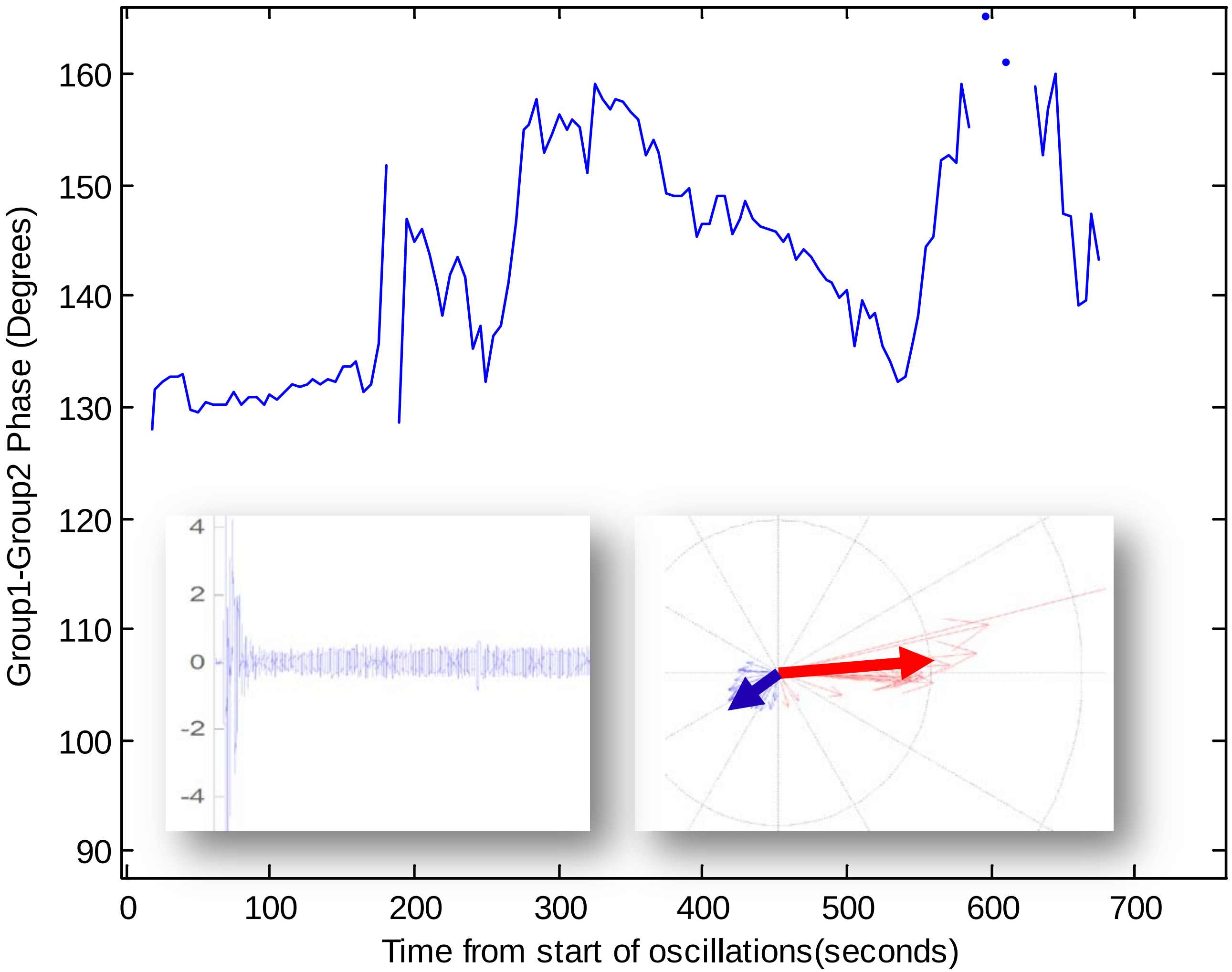
Group Phase difference



- First results obtained after 10 seconds.
- Group weighted average angles
- Group 1 is leading by 130-150º (i.e. leading by <180º), → **less damping provided by Group 1 than Group 2**.

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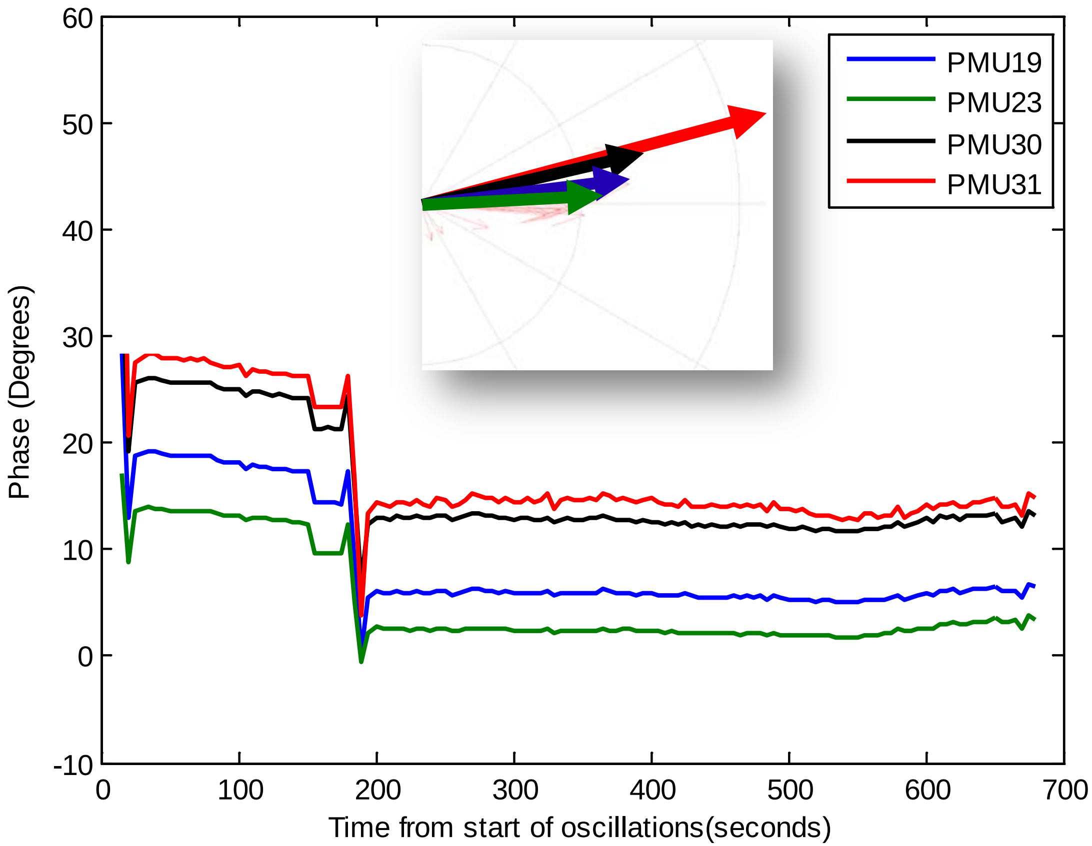
Most Leading Locations Within Group 1



- 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

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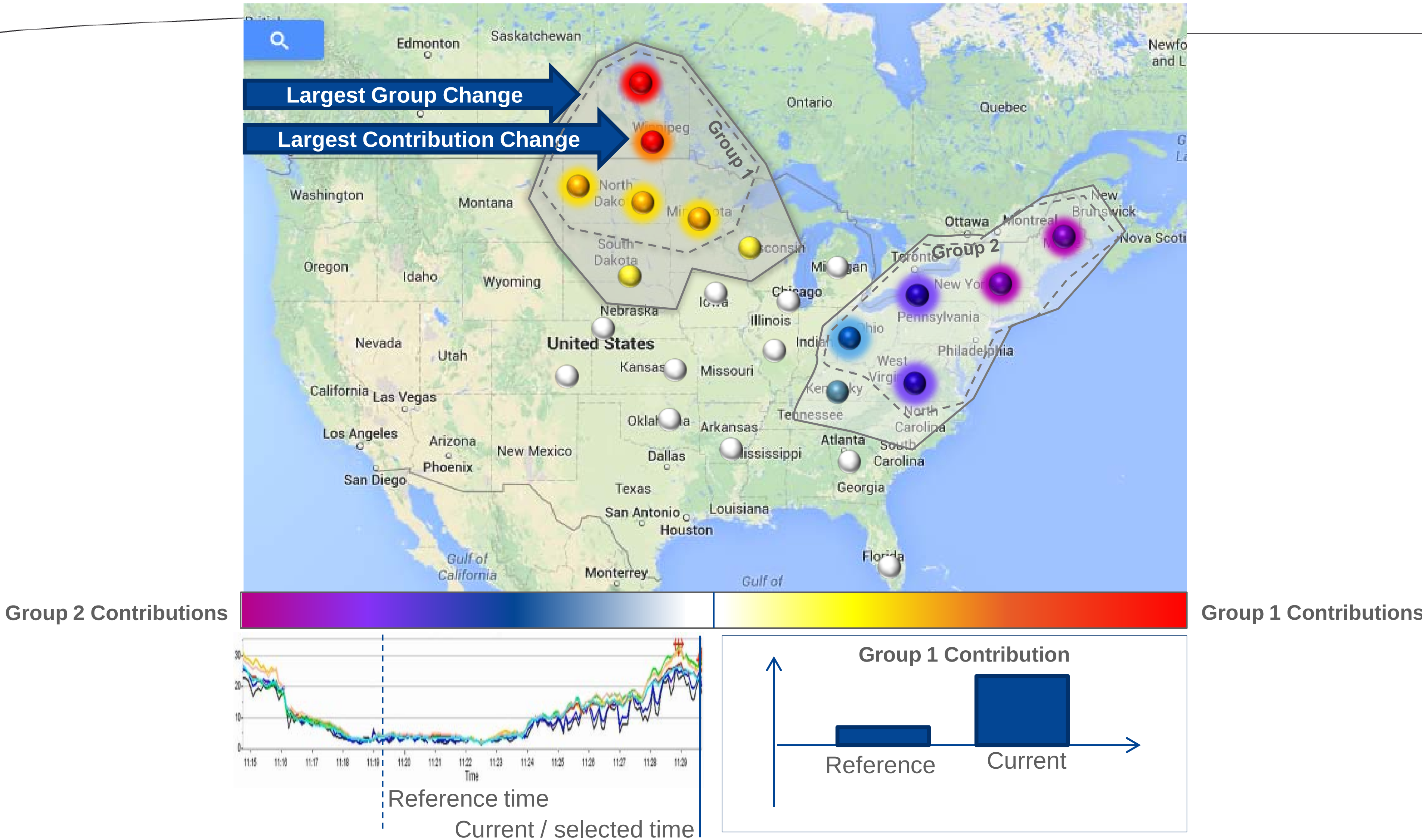
Application to Large Interconnection



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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

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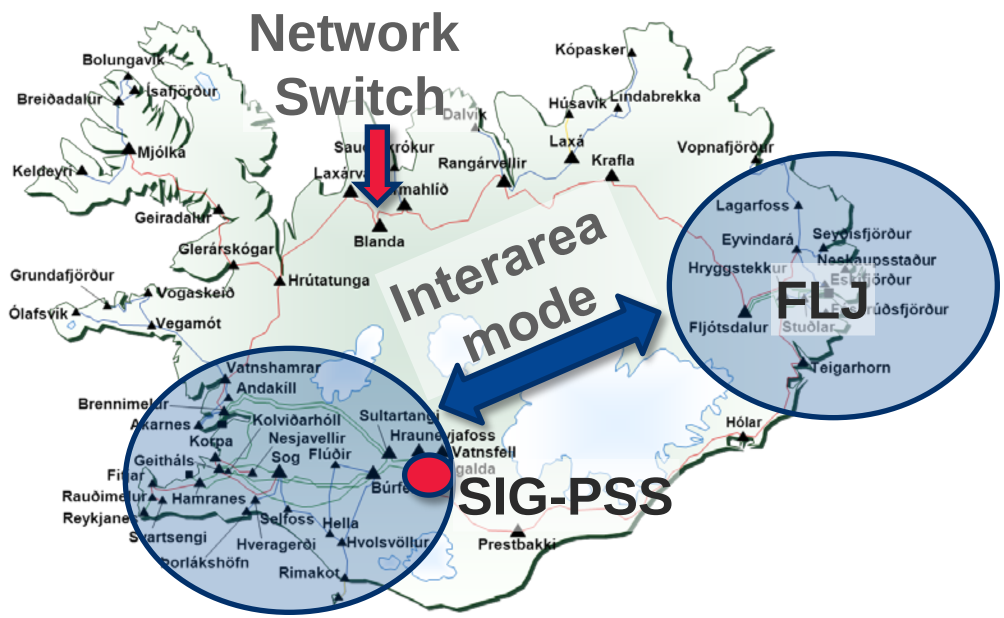
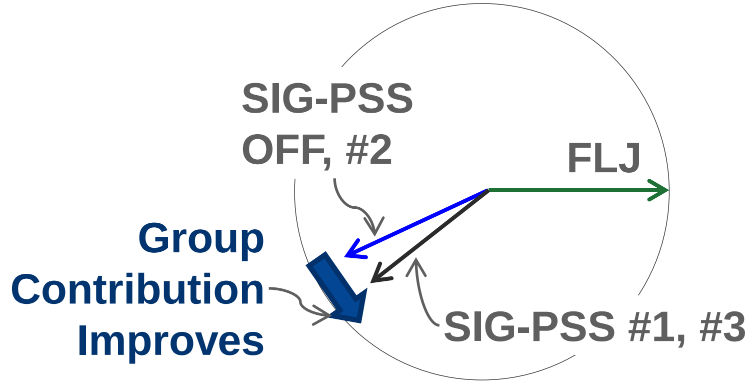
Application to PSS tuning

Identify damping contribution with different PSS settings

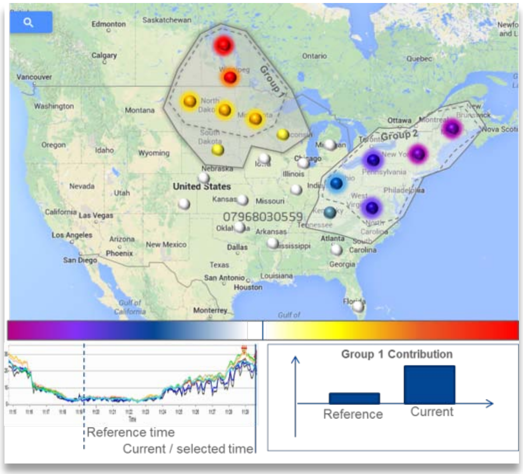


Switching Tests (opening)	Mode Frq	Damping	SIG-FLJ	Phase Change
PSS OFF	0.34	4.2%	-167.1	0
PSS #1 ON	0.33	6.8%	-156.2	10.9
PSS #2 ON	0.33	2.3%	-167.3	-0.2
PSS #3 ON	0.33	6.3%	-154.3	12.8



Conclusions

- Novel measurement-based oscillation source location
  - Applied to voltage phasors
  - Uses oscillation phase relationships for contributions
  - Not dependent on observing largest amplitude
- Applied to recorded example from ISO-NE
  - Instability at 0.9Hz observed throughout ISONE
  - Leading phase indicated source of oscillation (large amplitude only in 1 measurement)
  - Phase method gives correct outcome, even without the large-amplitude measurement
- Applicable from small systems to large interconnections
  - High-level wide-area view
  - Detailed control area view
- Applicable in Real-Time or Analysis timeframe



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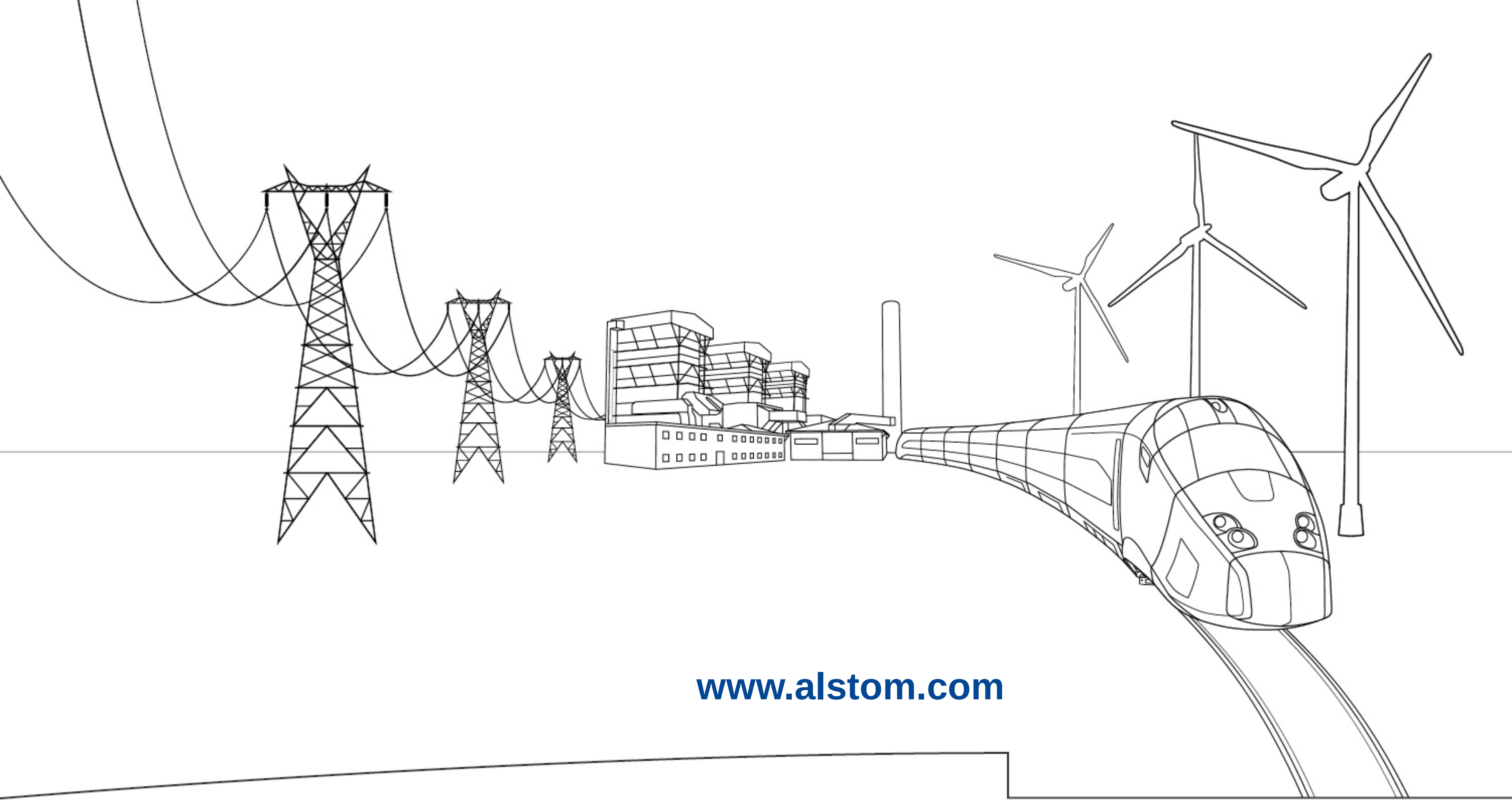

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