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Inter-area Oscillations in Power Systems

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Outline

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- What are Inter-area Oscillations?
- 6-Bus Example of Inter-area Oscillations
- Inter-area Oscillations in the WECC
- Mitigation Strategies
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Introduction

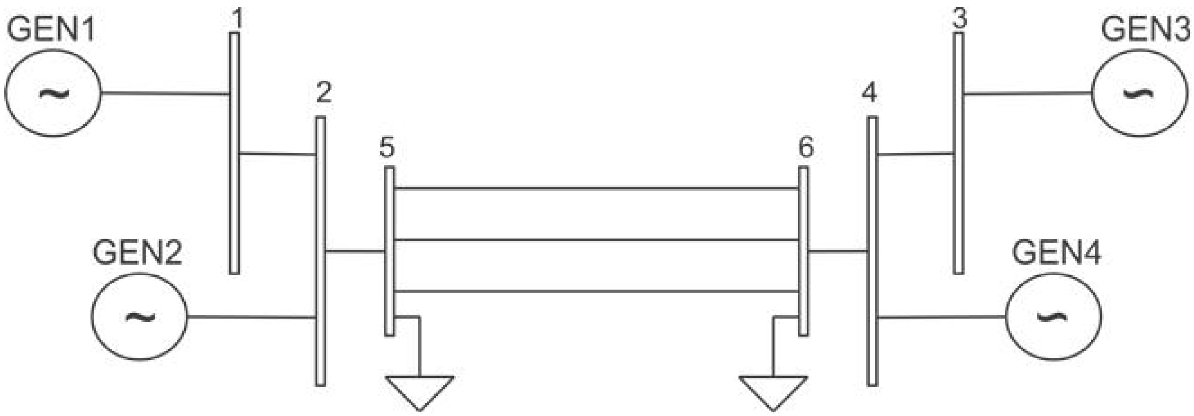
- The power system is operated in a conservative way
- Operation of the system closer to its stability limit saves money (e.g., transmission deferral).
- Inter-area oscillations are difficult to detect
- Inter-area oscillations can cause blackouts (e.g., WECC 1996)
- Loading of transmission paths follow several stability “limits” (e.g., thermal, voltage)
- Inter-area oscillations limits loading of transmission paths
- Building new transmission is a very expensive and time consuming task.
  - $1M - $4M / mile depending on voltage class (345kV-765kV), terrain, right of way, environmental mitigation requirements, etc.
  - 3-5 years for permitting, 2+ to build

What are Inter-area Oscillations?

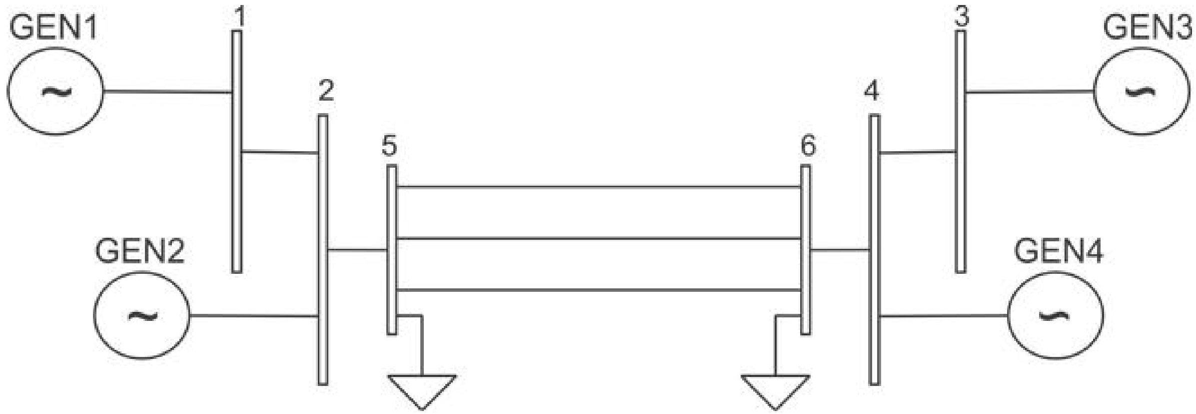
- Oscillations (modes) in power systems can be divided into:
  - Local modes
    - Oscillations associated with electrically “close” groups of generators.
    - Generally observed at frequencies >1 Hz.
    - Sometimes caused by inadequate tuning of control systems (exciters, HVDC converters, SVCs).
  - Inter-area modes
    - Oscillations associated with the flow of power between “electrically far” areas.
    - Generally observed at frequencies between 0.1-1 Hz.
    - Groups of generators in one area swinging against another group of generators in another area.
    - Occur across weak or heavily loaded transmission paths.
- Local and inter-area modes are small-signal stability issues.

Example of Inter-area Oscillations

- Small 2-area, 4-generators, 7-bus system
- Impedance of lines connecting areas 1 and 2 are approximately 10X higher than intra-area lines.
- PSLF simulation
- Fault at bus 5

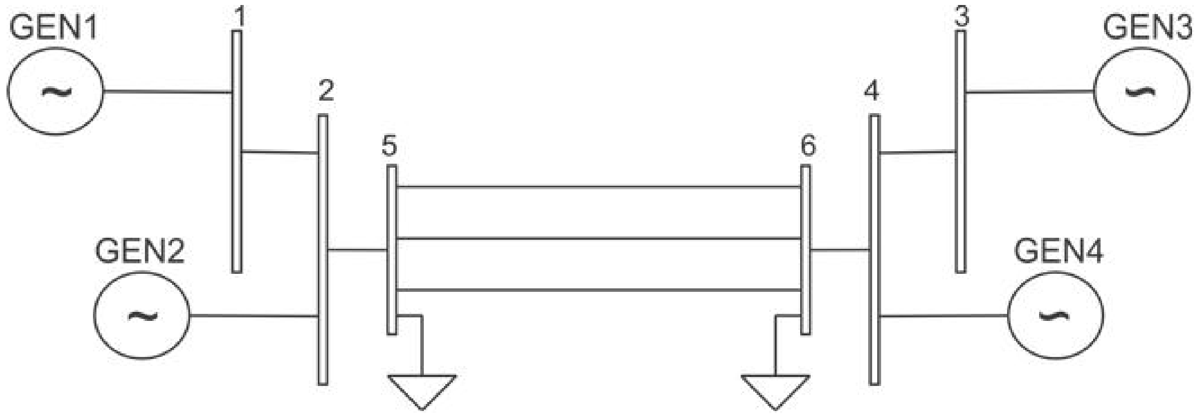


Thermal Generation



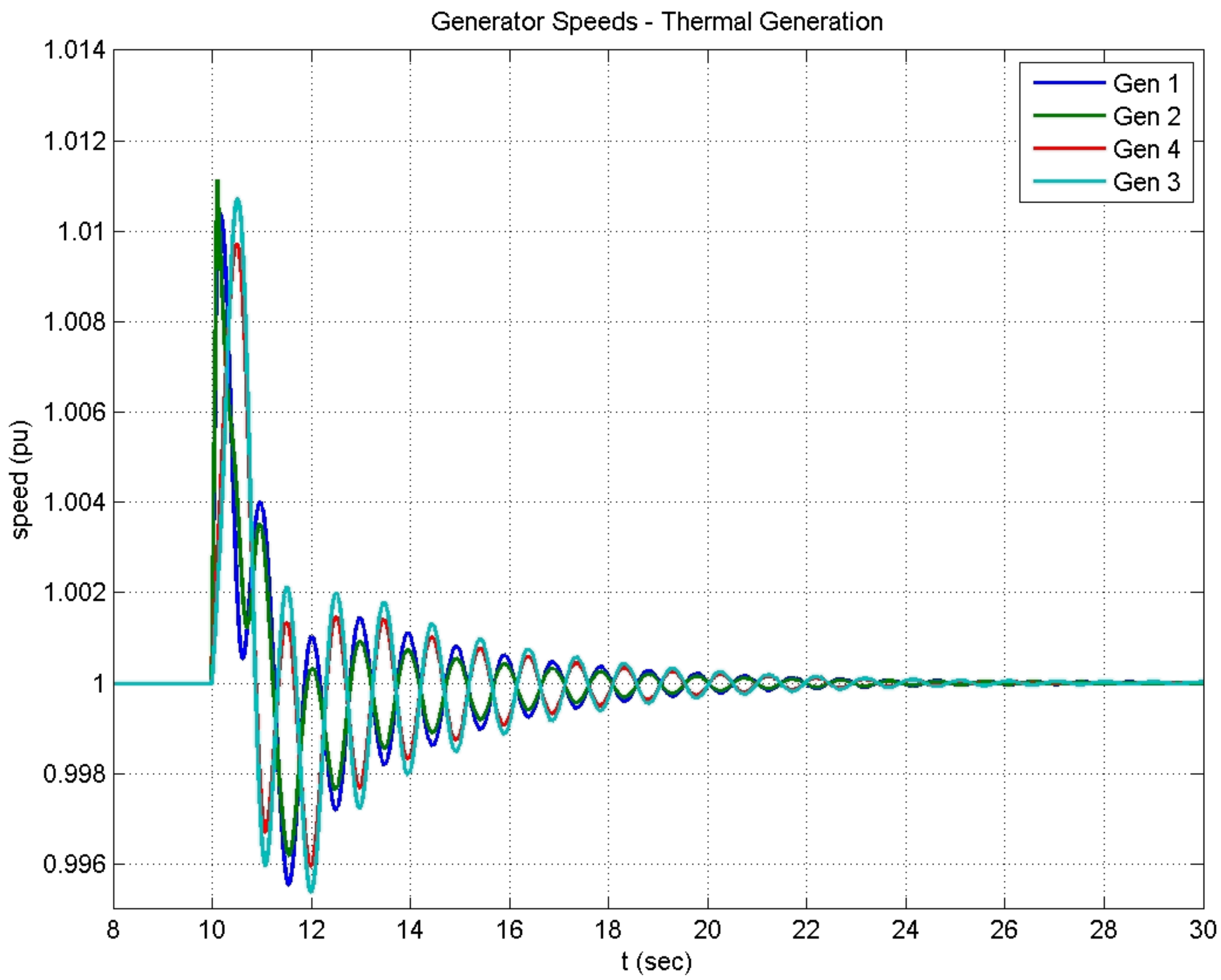
- Area 1
  - Load: 1,000 MW
  - Gen1: 900 MW (1,200 MVA), Gen2: 400 MW (600 MVA), total: 1,300 GW (1,800 MVA)
- Area 2
  - Load: 1,500 MW
  - Gen 3: 582.8 MW (1,050 MVA), Gen 4: 650 MW (1,050 MVA), Total: 1,233 MW (2,100 MVA)

Thermal + Wind Generation

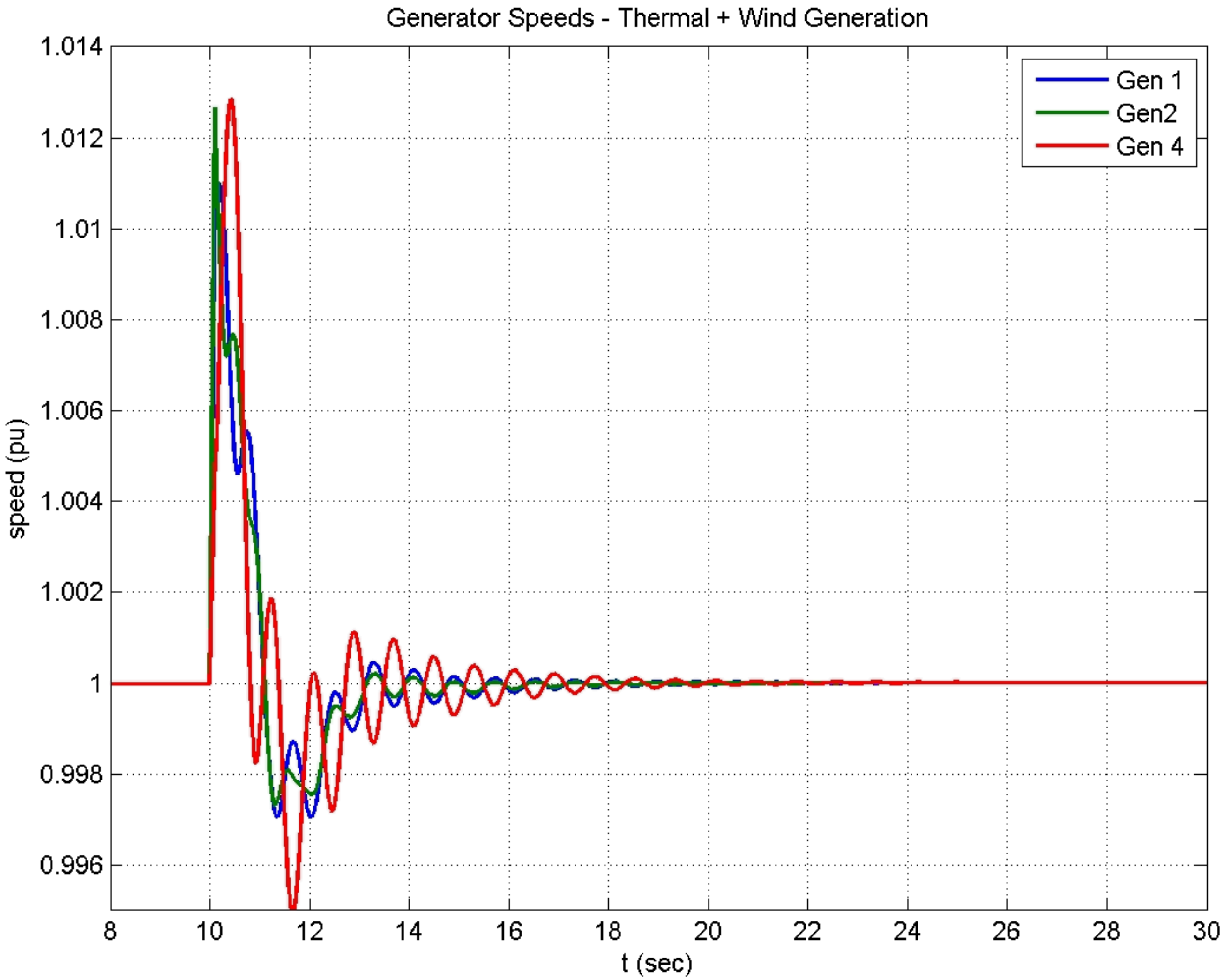


- Replace Gen 3 (Area 2) with a type 3 wind farm
- Asynchronous generator connected through power electronics
- No inertia contribution

Simulation Results - Thermal



Simulation Results – Thermal + Wind

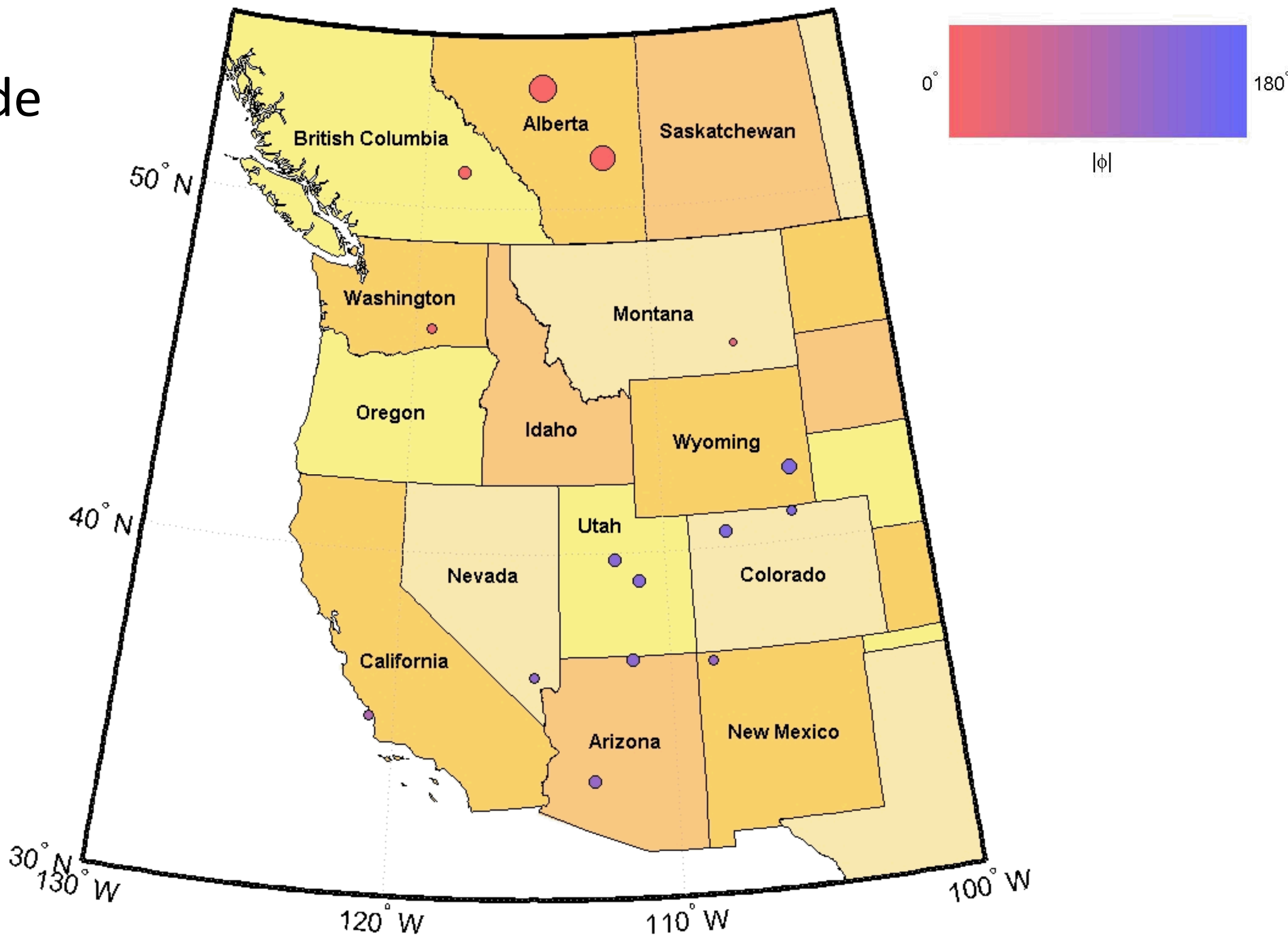


Inter-area Oscillations in the WECC

- PSLF models of the WECC for several cases were employed
- Small signal disturbance: 1.4GW breaker insertion (Chief Joe) at different buses in the system
- Generator speeds were tracked
- Mode shape was determine using Prony analysis
  - Damping
  - Frequency
  - Phase
- North – South Mode (N – S)
- Alberta – BC Mode (AB – BC)
- Other modes: BC Mode (0.6Hz) and Montana Mode (0.8Hz)

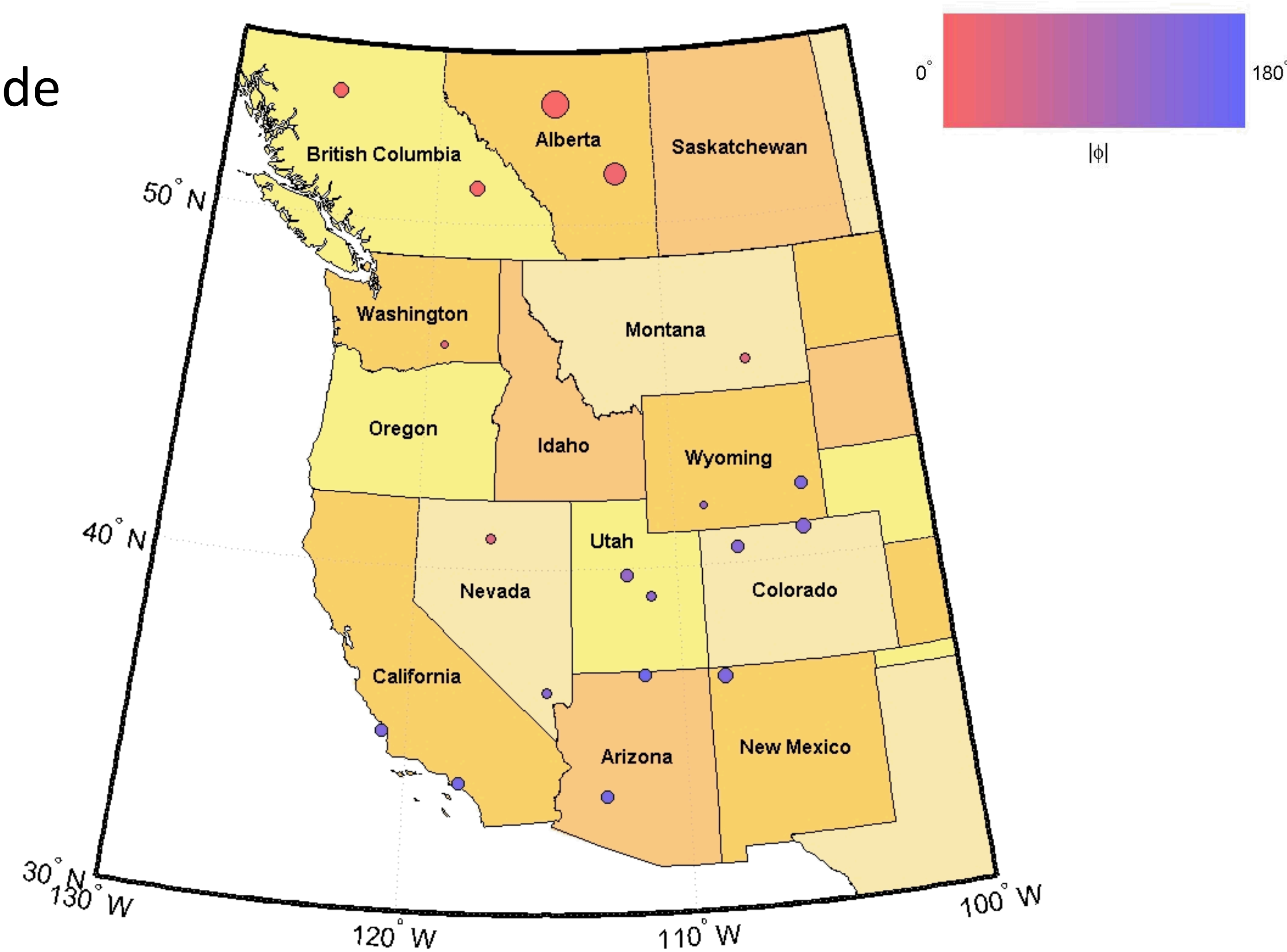
Light Summer 2012

- N-S Mode
- 0.24 Hz



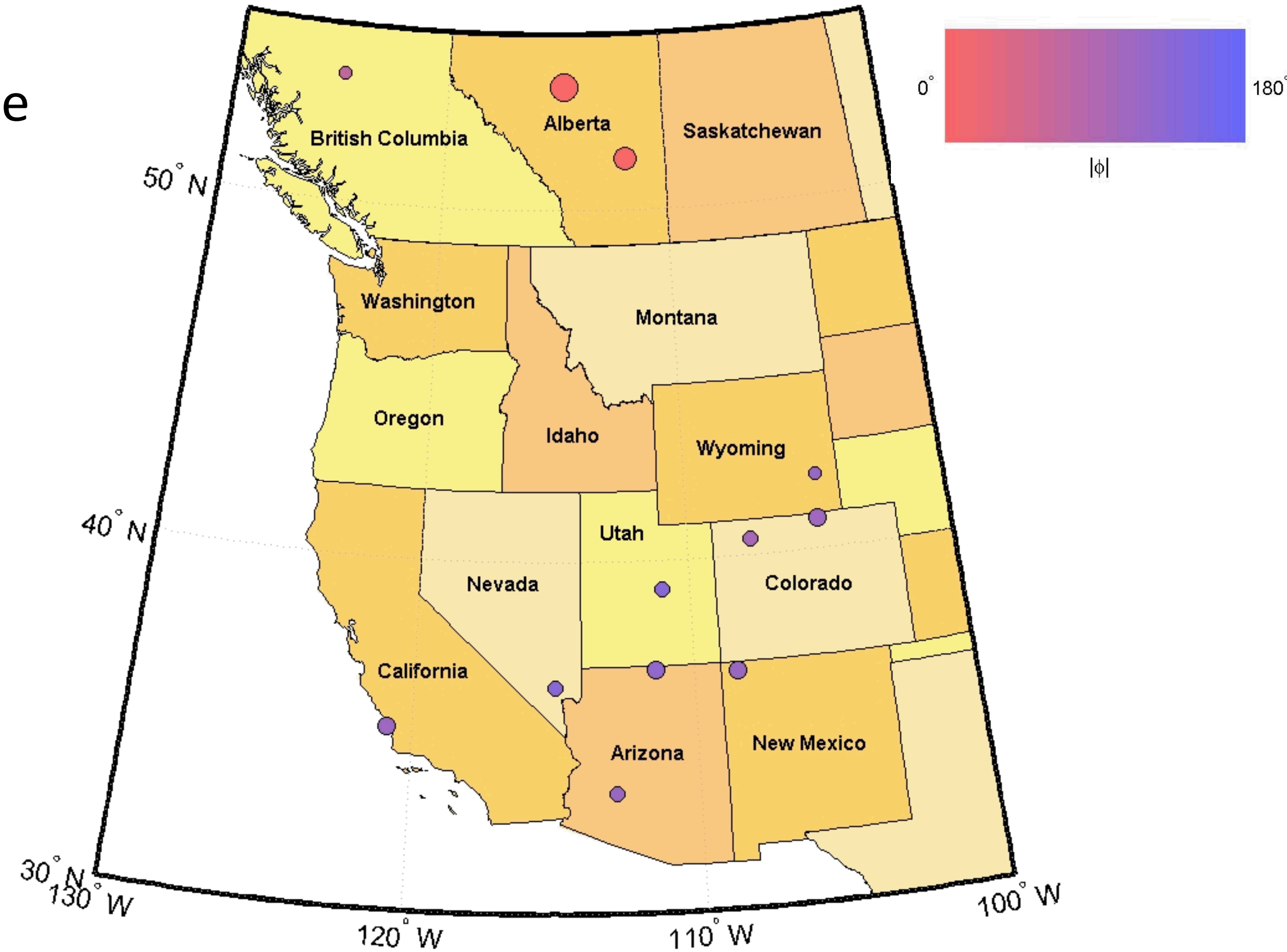
Light Summer 2022

- N – S Mode
- 0.29 Hz



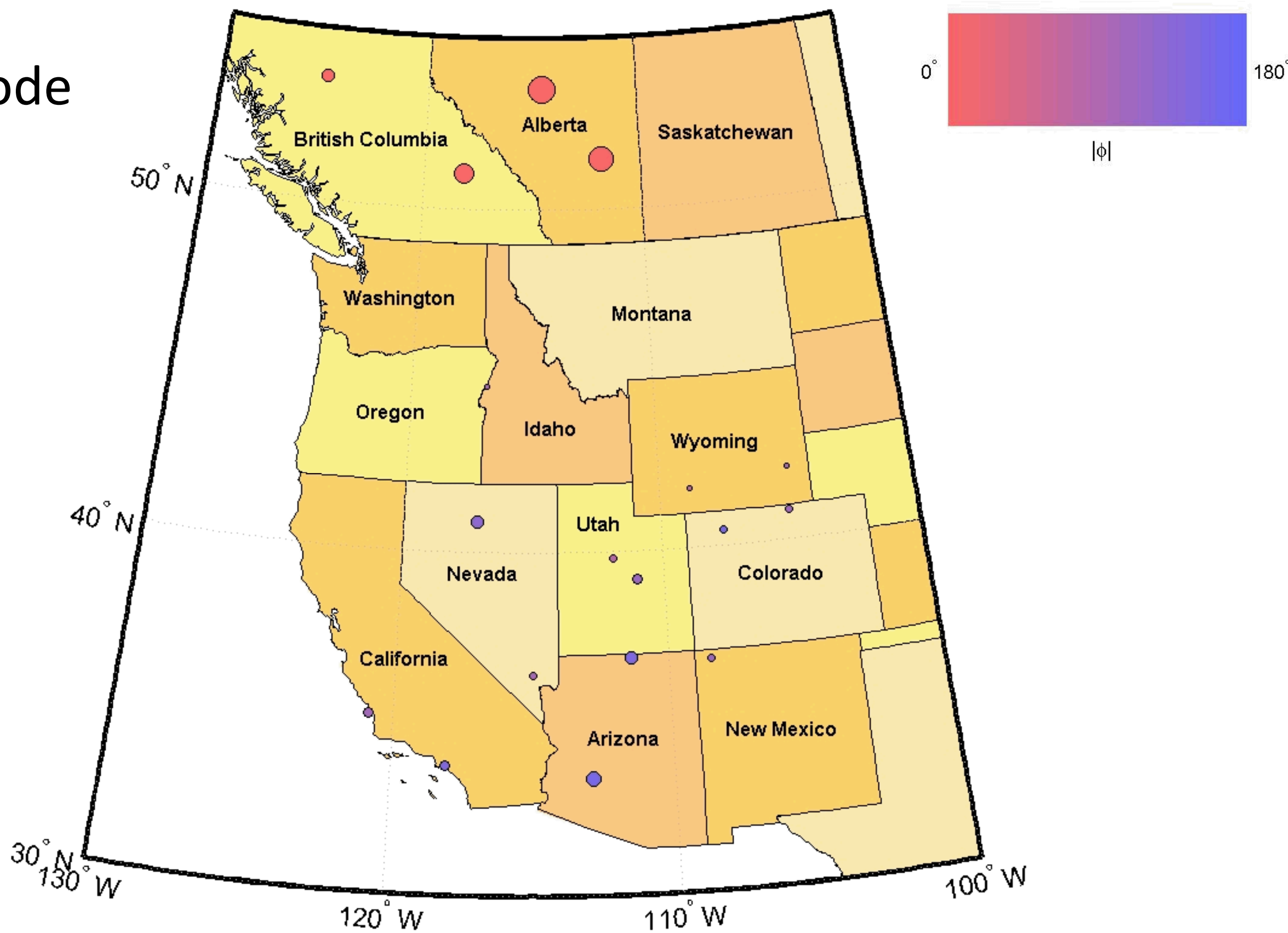
Heavy Winter 2012

- N-S Mode
- 0.24 Hz



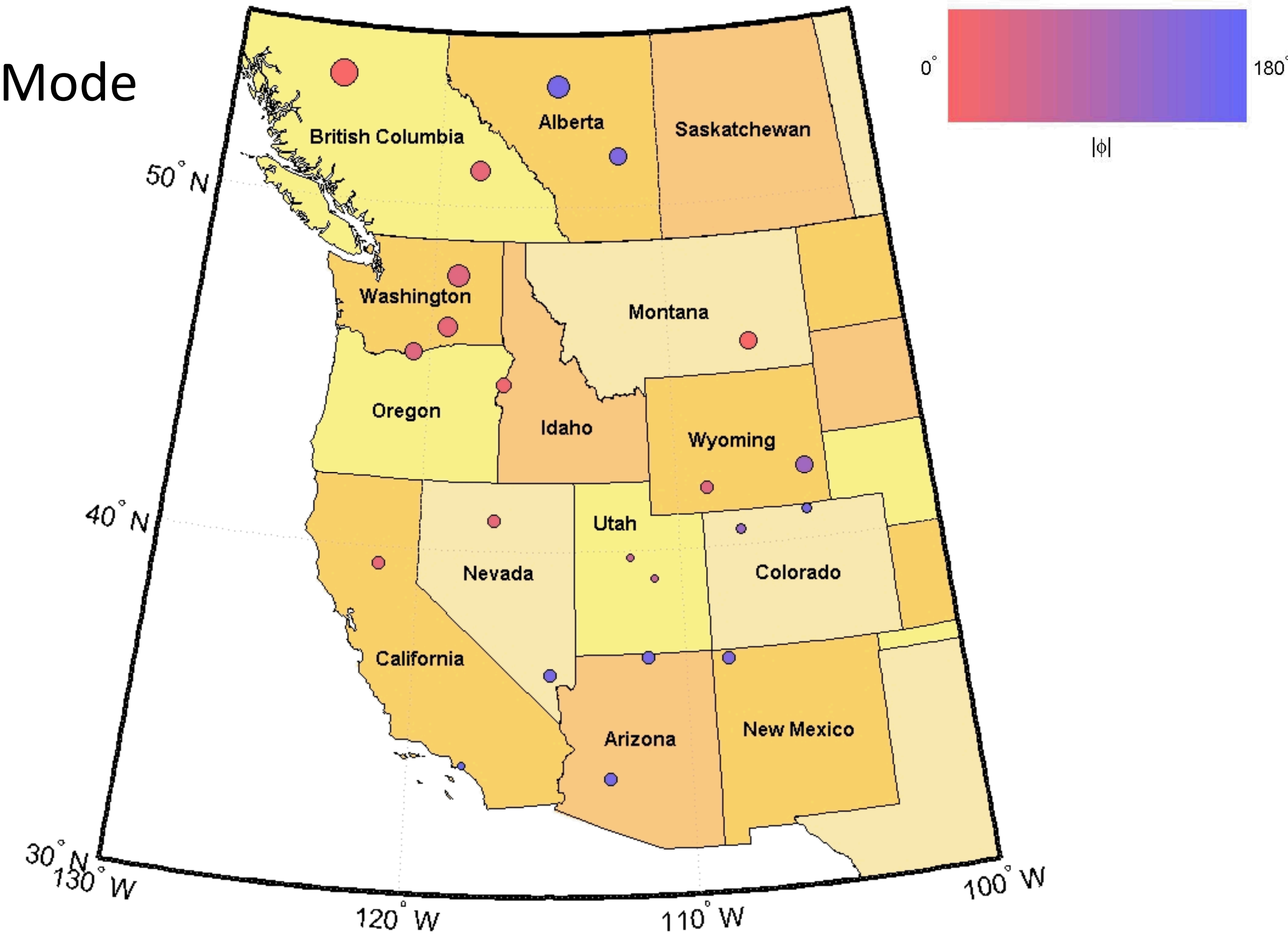
Heavy Winter 2022

- N – S mode
- 0.24 Hz



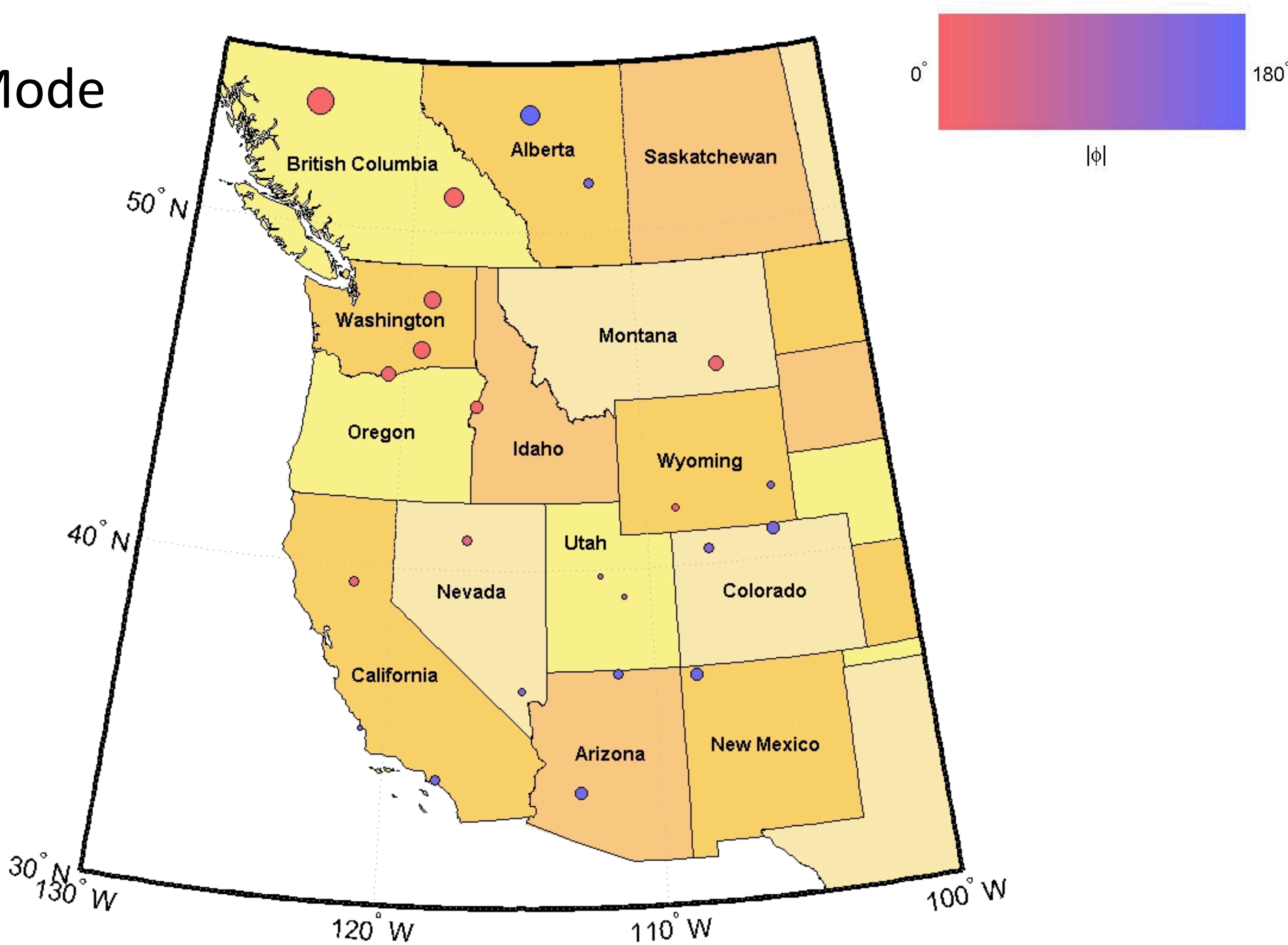
2012 Light Summer

- AB – BC Mode
- 0.40 Hz



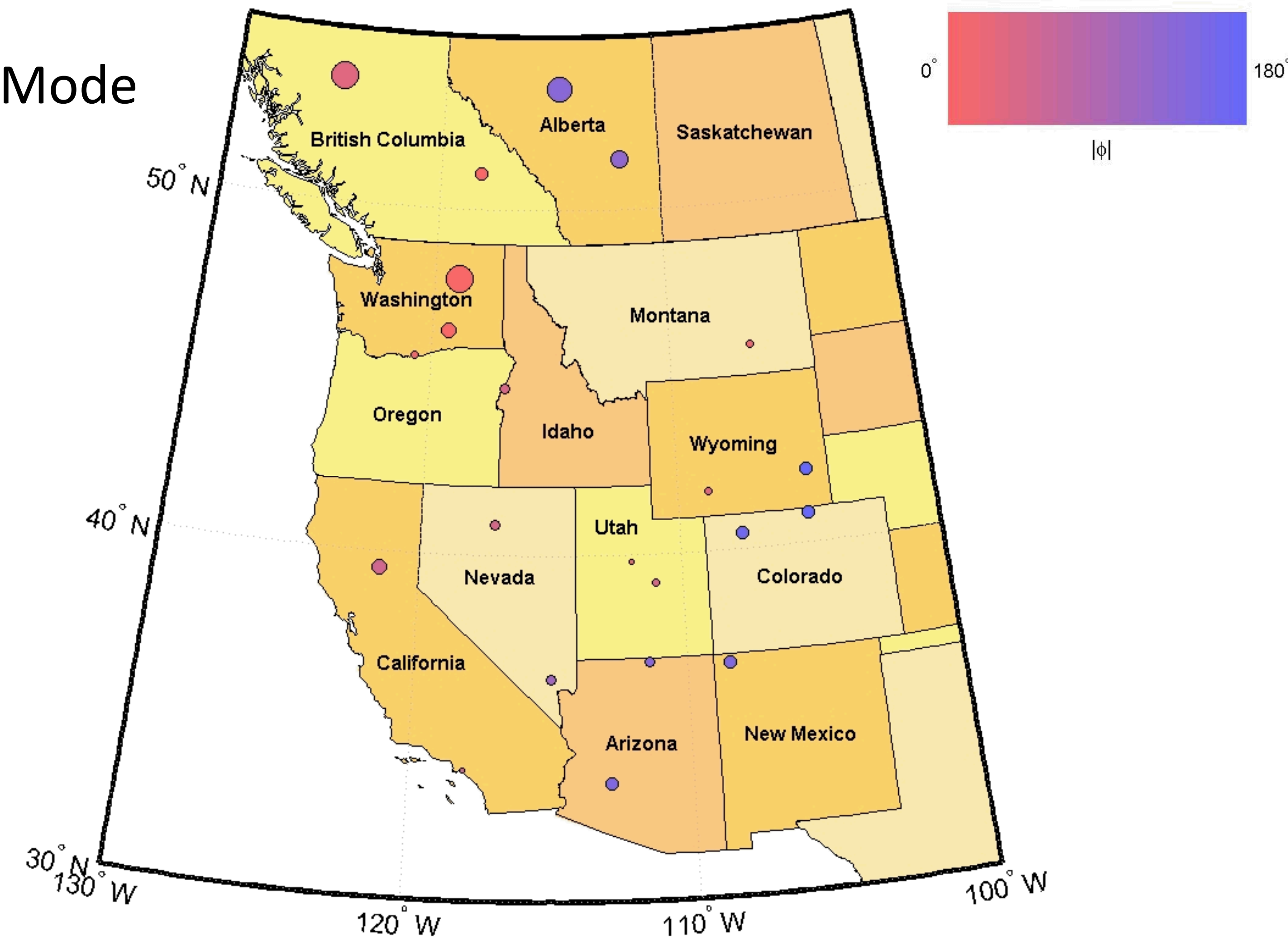
2022 Light Summer

- AB – BC Mode
- 0.47 Hz



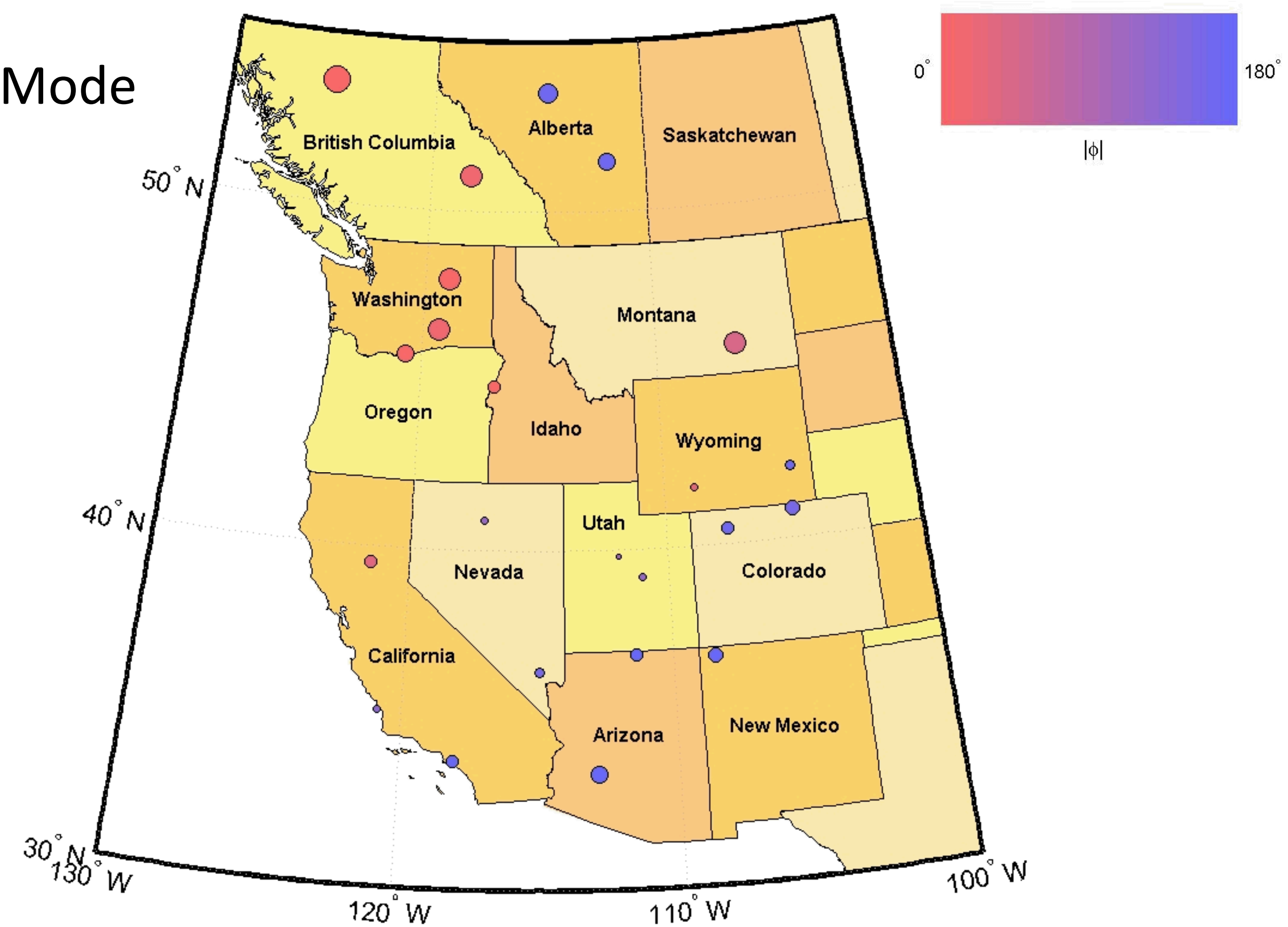
2012 Heavy Winter

- AB – BC Mode
- 0.35 Hz



2022 Heavy Winter

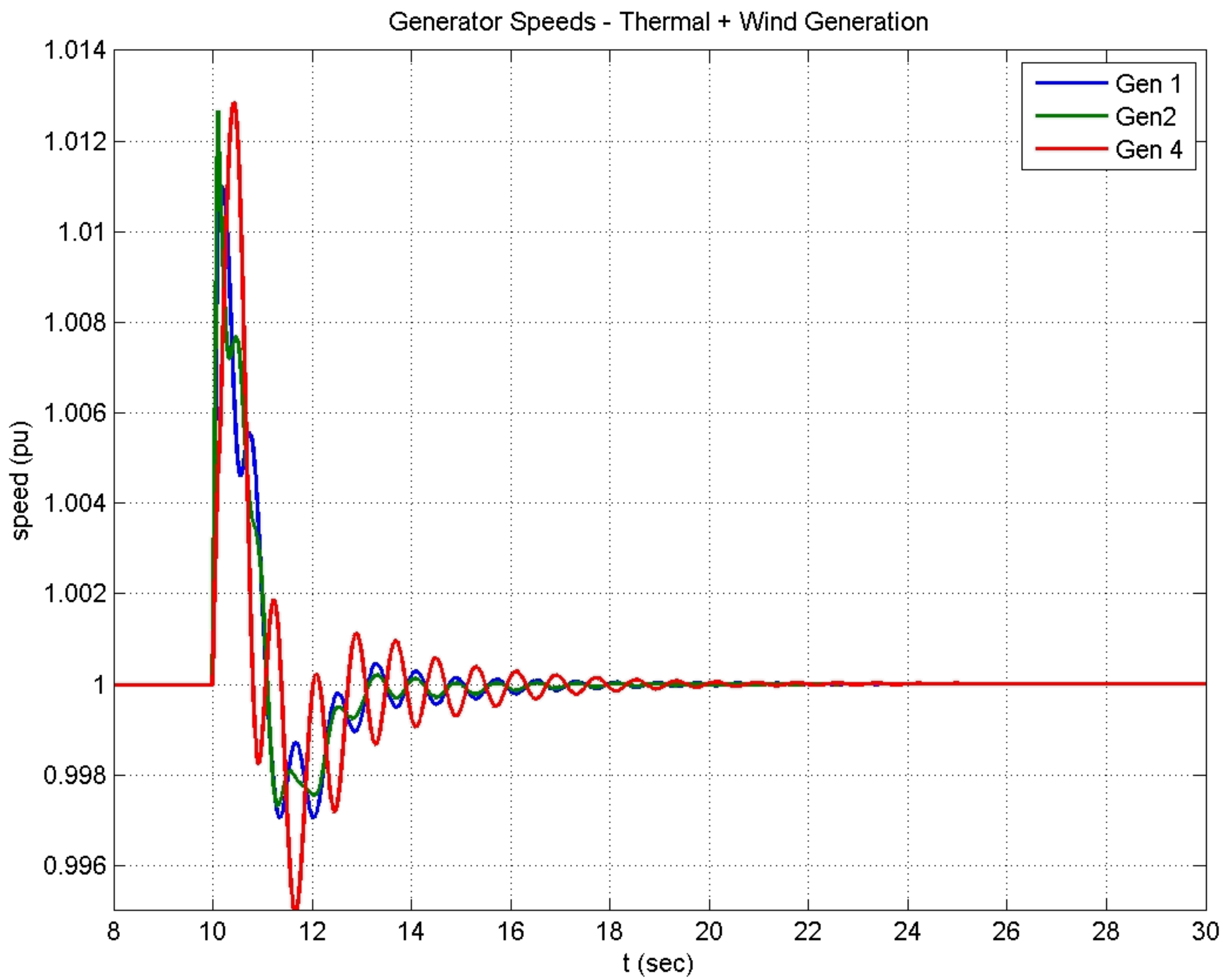
- AB – BC Mode
- 0.39 Hz



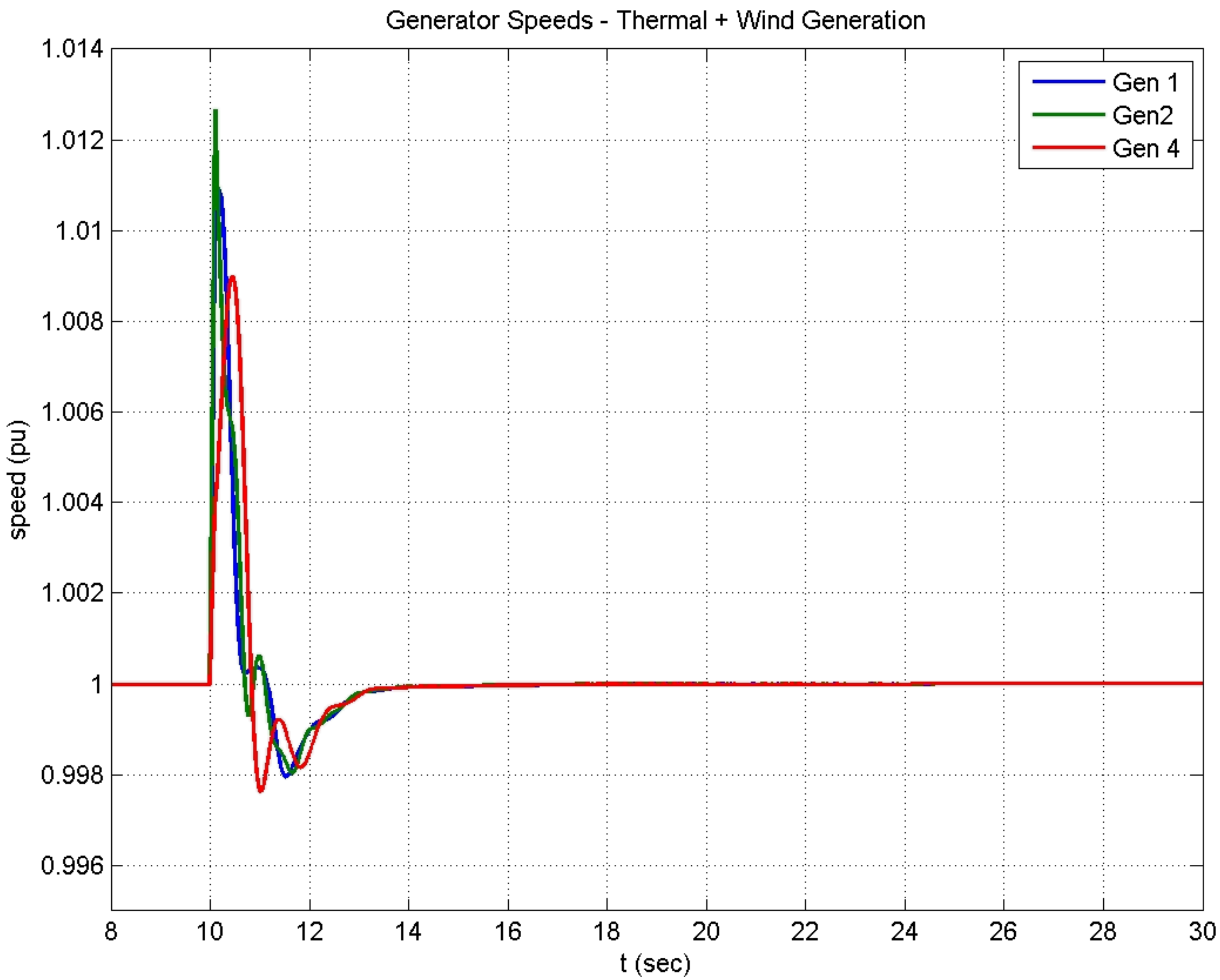
Mitigation Strategies

- Control of real power injection into the grid at strategic locations
  - Generators
  - Energy storage
  - HVDC converters
- Control of real power flow at strategic branches in the grid
  - FACTS
  - Transmission switching
- Control of reactive power injection into the grid at strategic locations
  - Power electronics based resources (e.g., wind and solar generation)
  - FACTS (e.g., SVCs)

Simulation Results – Thermal + Wind



Sim. Results - Thermal + Wind + Ctrl



Conclusions

- Increases in renewable generation penetration will change mode shapes in the WECC
- Modes seem to remain well damped, but it could change depending on the location of new renewable plants
- Active power control, using either curtailed wind plants or in combination with energy storage helps reduce inter-area oscillations

Acknowledgements

- U.S. Department of Energy, Office of Energy Delivery and Energy Reliability
- Dr. Imre Gyuk, program manager for energy storage
- Prof. Dan Trudnowski and Matt Donnelly at Montana Tech

Want to read more…

- *Renewable Source Controls for Grid Stability* by R. Byrne et al. SNL report, to be released Nov. 2012.
- *Power System Oscillations* by G. Rogers
- *Power System Stability and Control* by P. Kundur

QUESTIONS

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