Thirty Years after 1996
WECC Oscillations Then and Now

Aug. 2026

NASPI webinar

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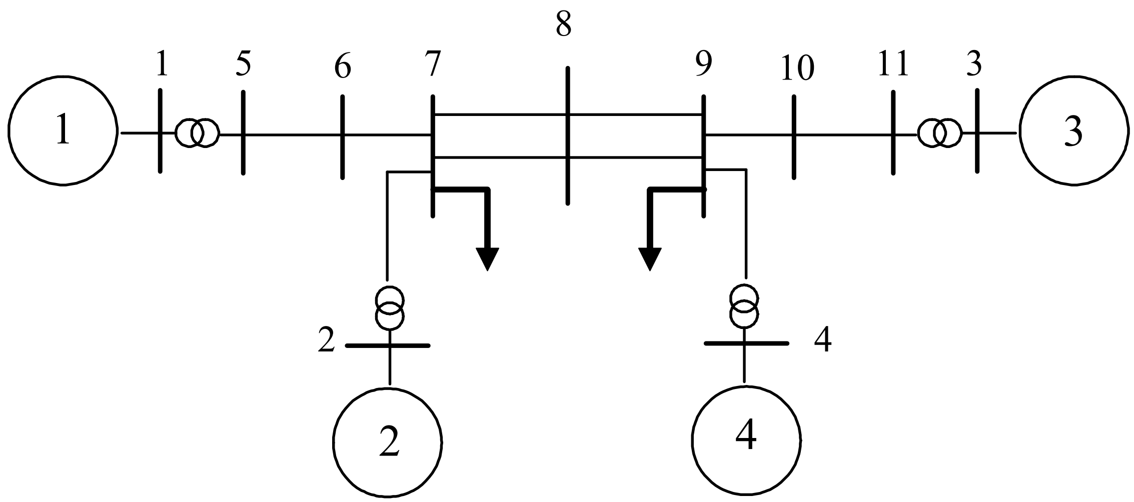
Electromechanical Modes

Modes

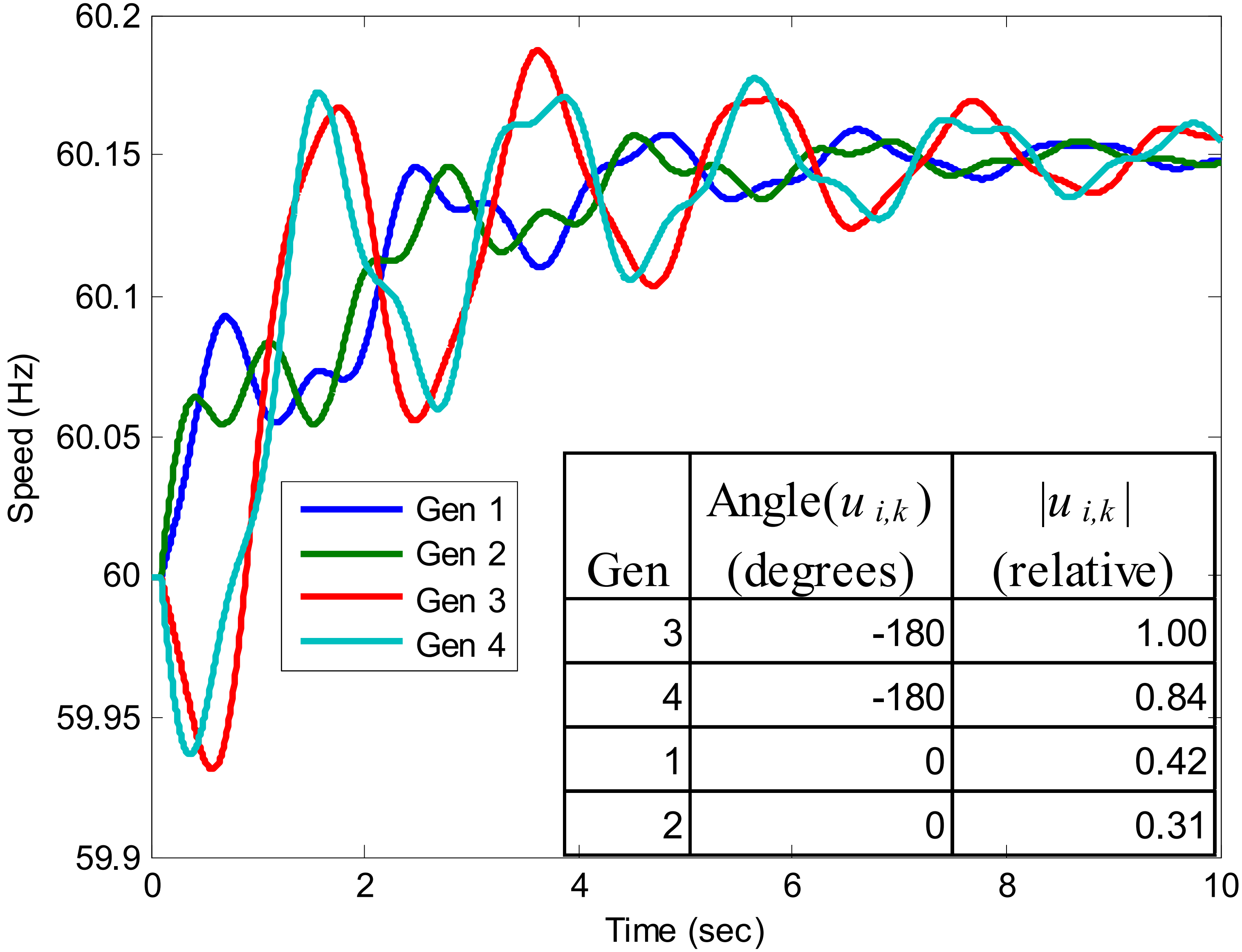
Frequency, Damping, Shape



Mode	Frequency (Hz)	Damping (%)
1	0.51	7.80
2	1.19	3.40
3	1.22	3.30

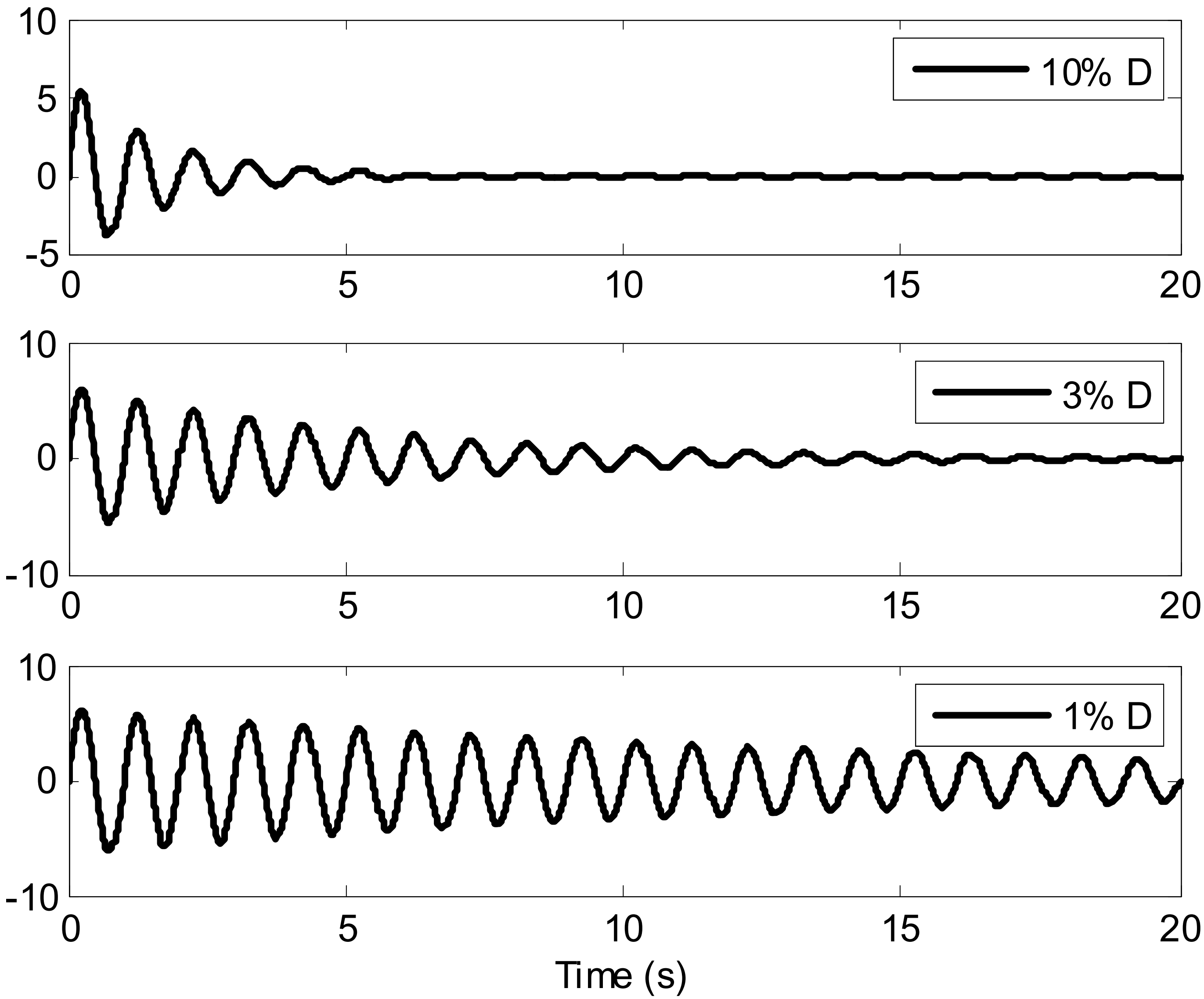
Gen	Angle($u_{i,k}$) (degrees)	Amplitude $\lvert u_{i,k}\rvert$
3	-180	1.00
4	-180	0.84
1	0	0.42
2	0	0.31

Mode Shape



Gen	Angle($u_{i,k}$) (degrees)	$\lvert u_{i,k} \rvert$ (relative)
3	-180	1.00
4	-180	0.84
1	0	0.42
2	0	0.31

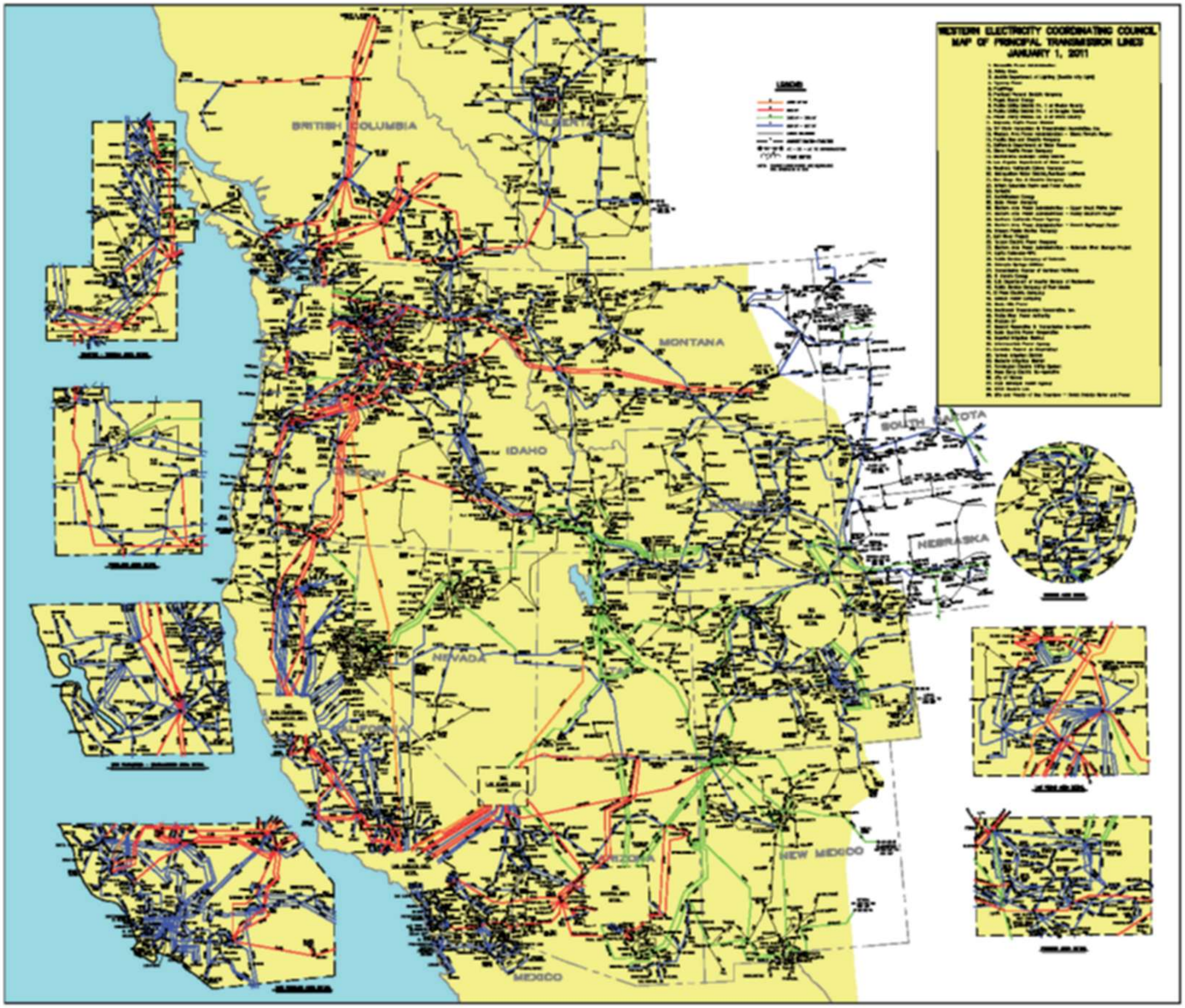
Damping



10
5
0
-5
10% D
0
5
10
15
20
10
0
-10
3% D
0
5
10
15
20
10
0
-10
1% D
0
5
10
15
20
Time (s)

Background

Western Interconnect



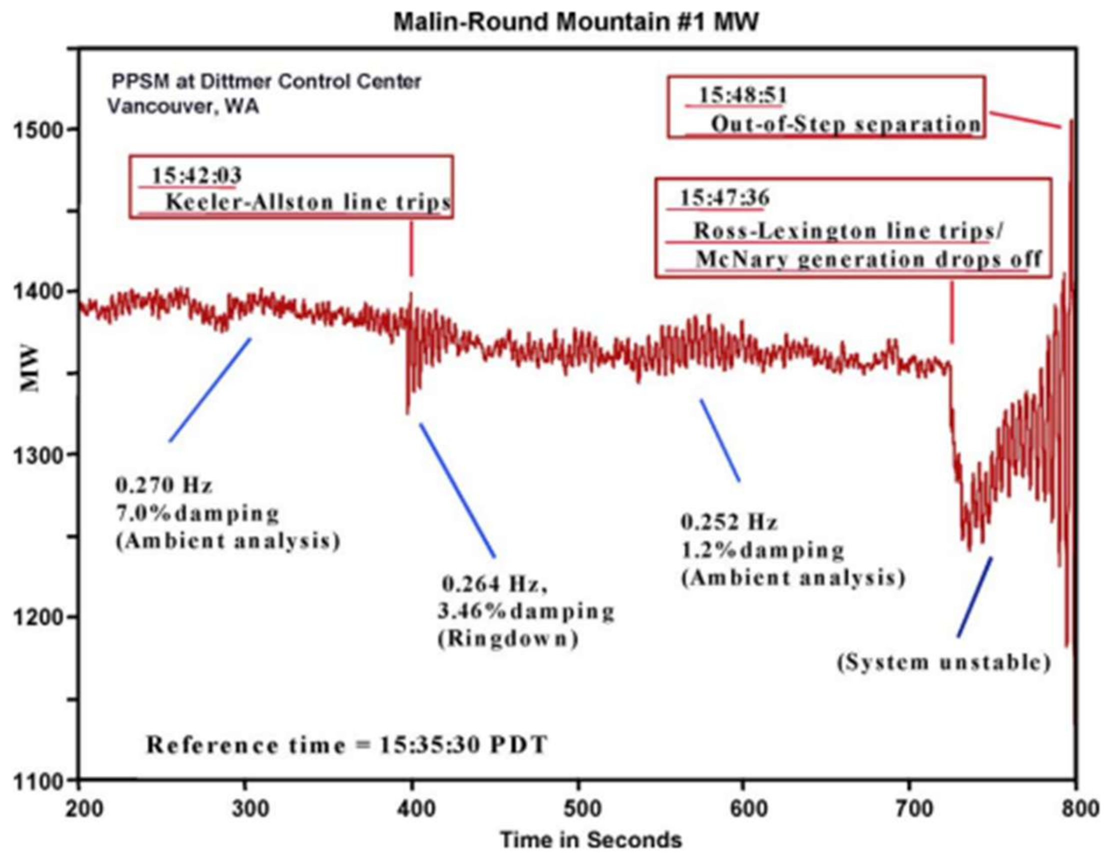
Historical Perspective

- 1967 – Pacific NW and SW were connected via 500-kV AC intertie (i.e., the COI).
- 1970 – Pacific DC Intertie (PDCI) constructed.
- 1970s – Several very lightly damped ~0.3 Hz oscillations observed on the AC intertie.
- 1978 – PDCI modulation control prototype installed to dampen AC intertie oscillations. Eventually shut off because of de-stabilizing effects due to lack of wide-area measurements.
- ~1980 – First emergence of a 2nd NS mode (what we now call NSA mode). Corresponded with Alberta interconnect?
- 1980s thru early 1990s – AC intertie mode damping became less with the advent of fast exciters, Canadian interconnect, higher transmission flows.
- **Aug. 10, 1996 – System oscillatory instability event**.
- 1990s thru early 2000s - the system had several low-damping events for the NSB mode.
- 2010 thru 2018 – Prototype wide-area PDCI damping controller researched, designed, installed, and tested. Currently not operating.
- ~2015 thru today - Damping issues started to subside as more solar power in So. CA significantly changed COI flows.

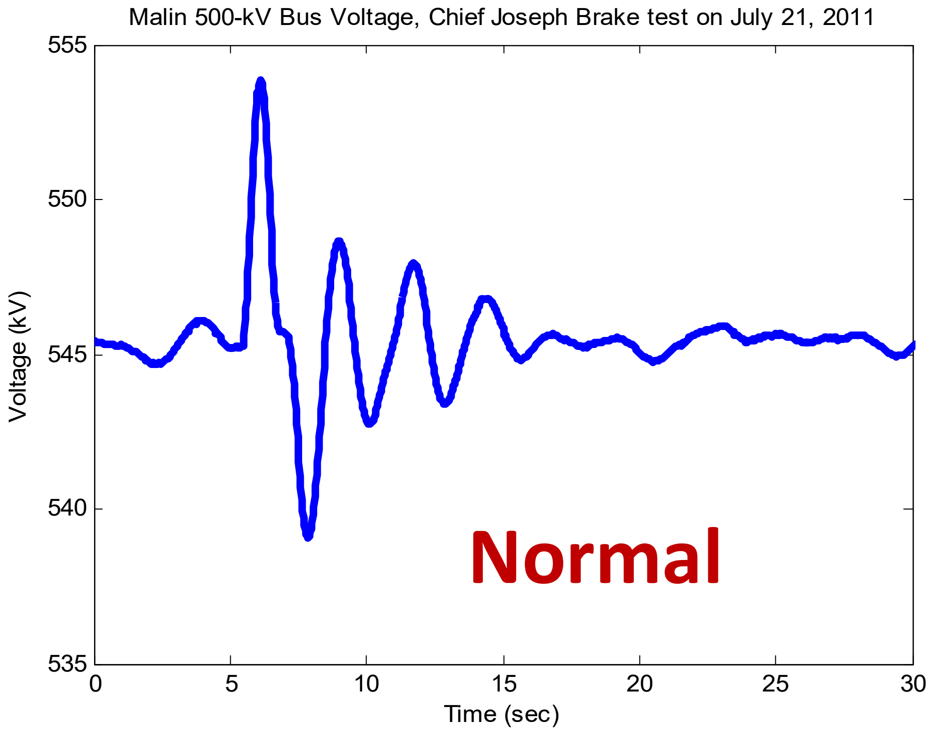
References

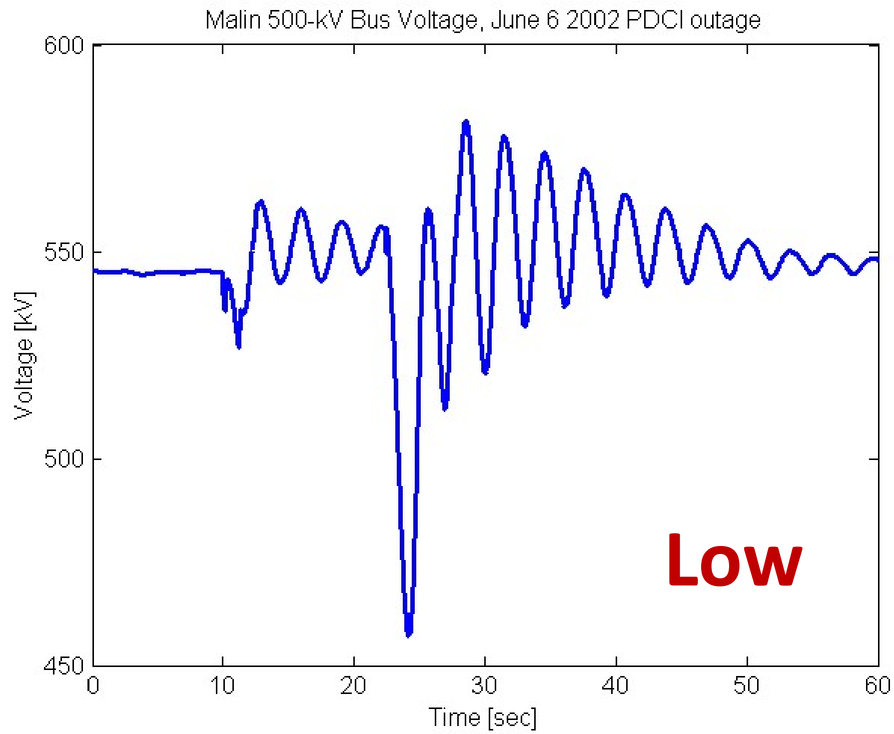
1. Cresap, Mittelstadt, Scott, and Taylor, "Operating experience with modulation of the Pacific HVDC intertie," *IEEE Trans. PAS*, vol. PAS-97, no. 4, pp. 1053-1059, 1978.
   - Addresses damping control of the 0.3-Hz "Pacific AC Intertie Mode" via PDCI modulation.
   - Today, we term this NSB Mode.
   - Discusses the instability of this mode
   - Eventually, the control was turned off because it de-stabilized other modes (the BC mode).
2. Cresap and Hauer, "Emergence of a new swing mode in the wester power system," *IEEE Trans. PAS*, vol. PAS-100, no. 4, pp. 2037-2045, 1981.
   - First paper to discuss and measure the actual exsistance of multiple NS modes.
3. **Kosterev, Taylor, and Mittelstadt, "Model validation for the August 10, 1996 WSCC system outage," *IEEE Trans on PS*, vol. 14, no. 3, pp. 967-979, 1999**.
   - Detailed overview on the event
   - A must read!
4. Rogers, Elliott, Trudnowski, Wilches-Bernal, Osipov, and Chow, <u>Power System Oscillations</u>, 2nd Ed., Springer 2025
   - Overview of oscillation theory
   - Has extensive background and literature referencing for modal analysis
   - Chapter on wide-area PDCI damping control
5. D. Trudnowski, J. Follum, R. Elliott, D. Schoenwald, and J. Pierre, "Characterizing the oscillatory properties of bulk electric systems," *IEEE Access*, vol. 13, pp. 32883-32900, 2025.
   - Details the current knowledge of the WECC modes
   - Summary of the WECC/JSIS report (https://www.wecc.org/wecc-document/3011)
   - Pending addendum on BC modes.

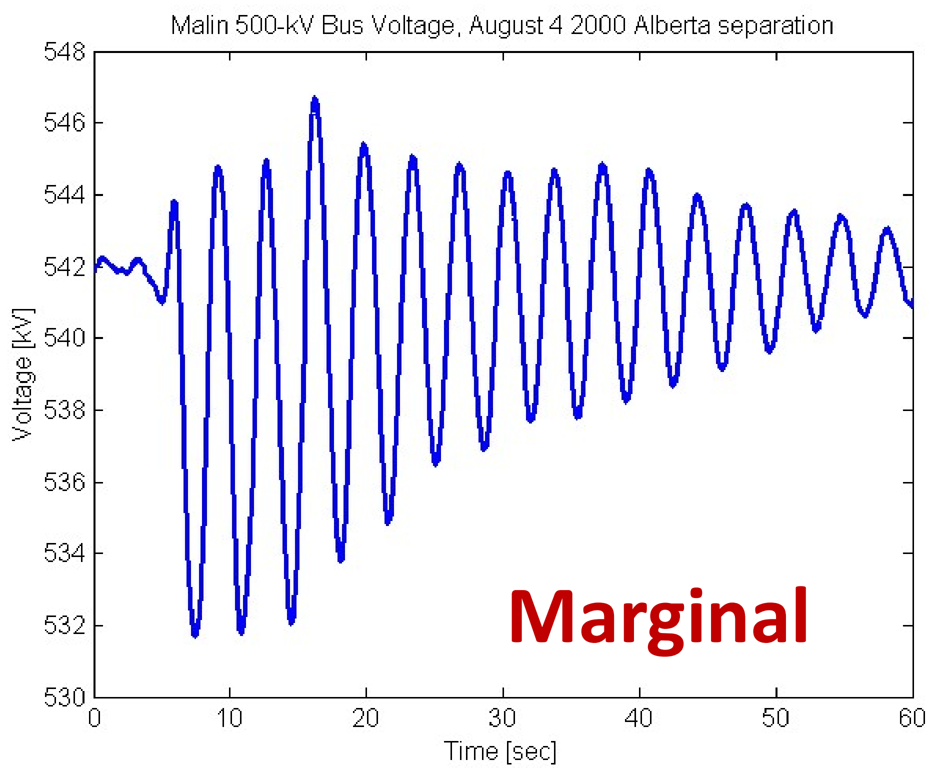
The Event

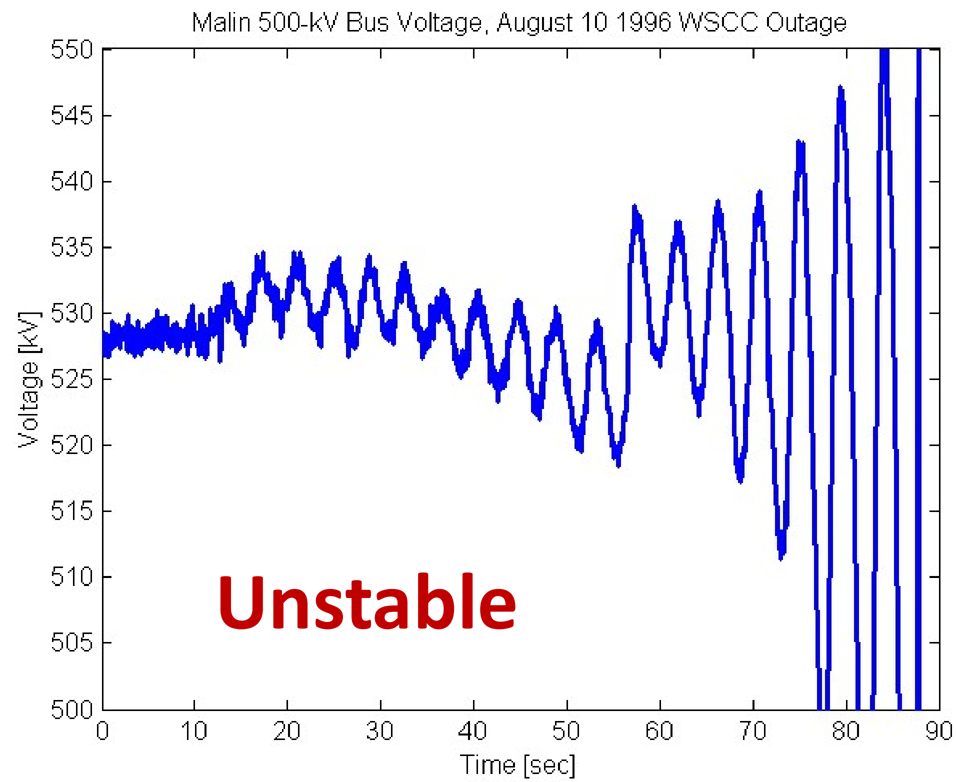


- High transmission loading in the pre-contingency
- Several key 500-kV lines were out of service for maintenance.
- Contingencies:
  - Keeler-Alston line trip further increased transmission loading
  - McNary generation tripping (from exciter protection malfunctions) tipped the system into instability.
  - System broke into 4 islands. 31 GW of lost load. System restoration took many hours.
- System wide oscillations
  - North vs. South
  - No wide-area synchronized monitoring was available in 1996, therefore, no detailed information on mode shape


Malin 500-kV Bus Voltage, Chief Joseph Brake test on July 21, 2011
Voltage (kV)
Time (sec)
555
550
545
540
535
0
5
10
15
20
25
30
Normal


Malin 500-kV Bus Voltage, June 6 2002 PDCI outage
Voltage [kV]
Time [sec]
600
550
500
450
0
10
20
30
40
50
60
Low


Malin 500-kV Bus Voltage, August 4 2000 Alberta separation
Voltage [kV]
Time [sec]
548
546
544
542
540
538
536
534
532
530
0
10
20
30
40
50
60
Marginal

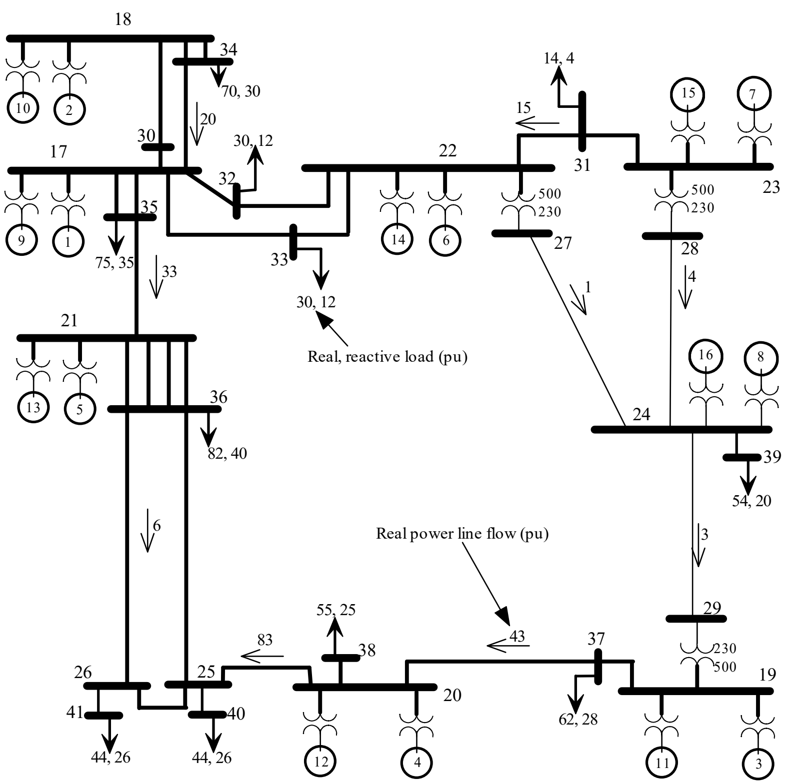

Malin 500-kV Bus Voltage, August 10 1996 WSCC Outage
Voltage [kV]
Time [sec]
550
545
540
535
530
525
520
515
510
505
500
0
10
20
30
40
50
60
70
80
90
Unstable

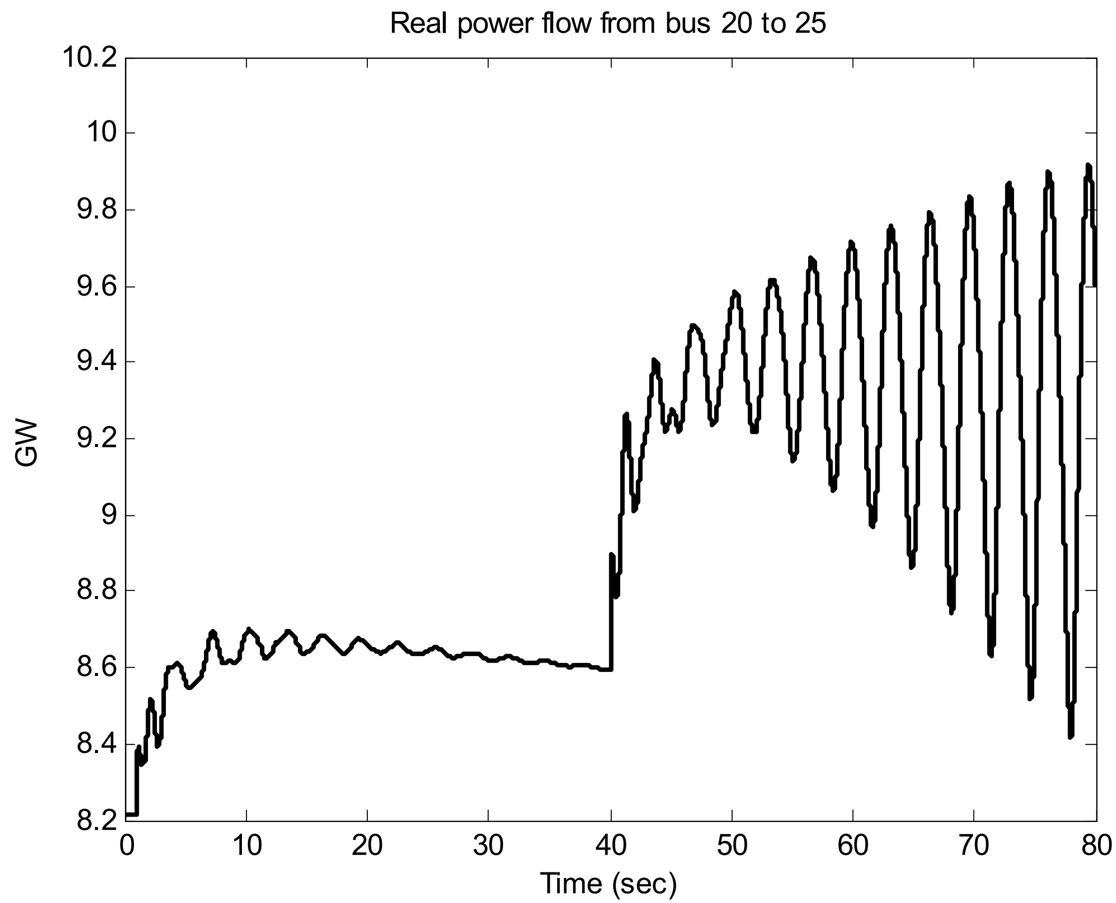
Post-Mortem Conclusions

- The unstable oscillations were a classical electro-mechanical instability
  - compounded by
    - High transmission loading
    - voltage depressions and excitation limiting
- Simulation
  - Initially, transient simulation results did not match the actual system
  - Model improvements did result in a close match
    - PDCI, AGC, Governor blocking on steam units, Dynamic loads
- Key PSS units tuned to interarea modes might have prevented the instability.
- Minimal actual-system modal analysis was done
  - System wide-area synchronized (PMU) monitoring did not yet exist. Therefore, no way to obtain the mode shape.
  - Signal processing algorithms were minimal (Prony was a new tool).

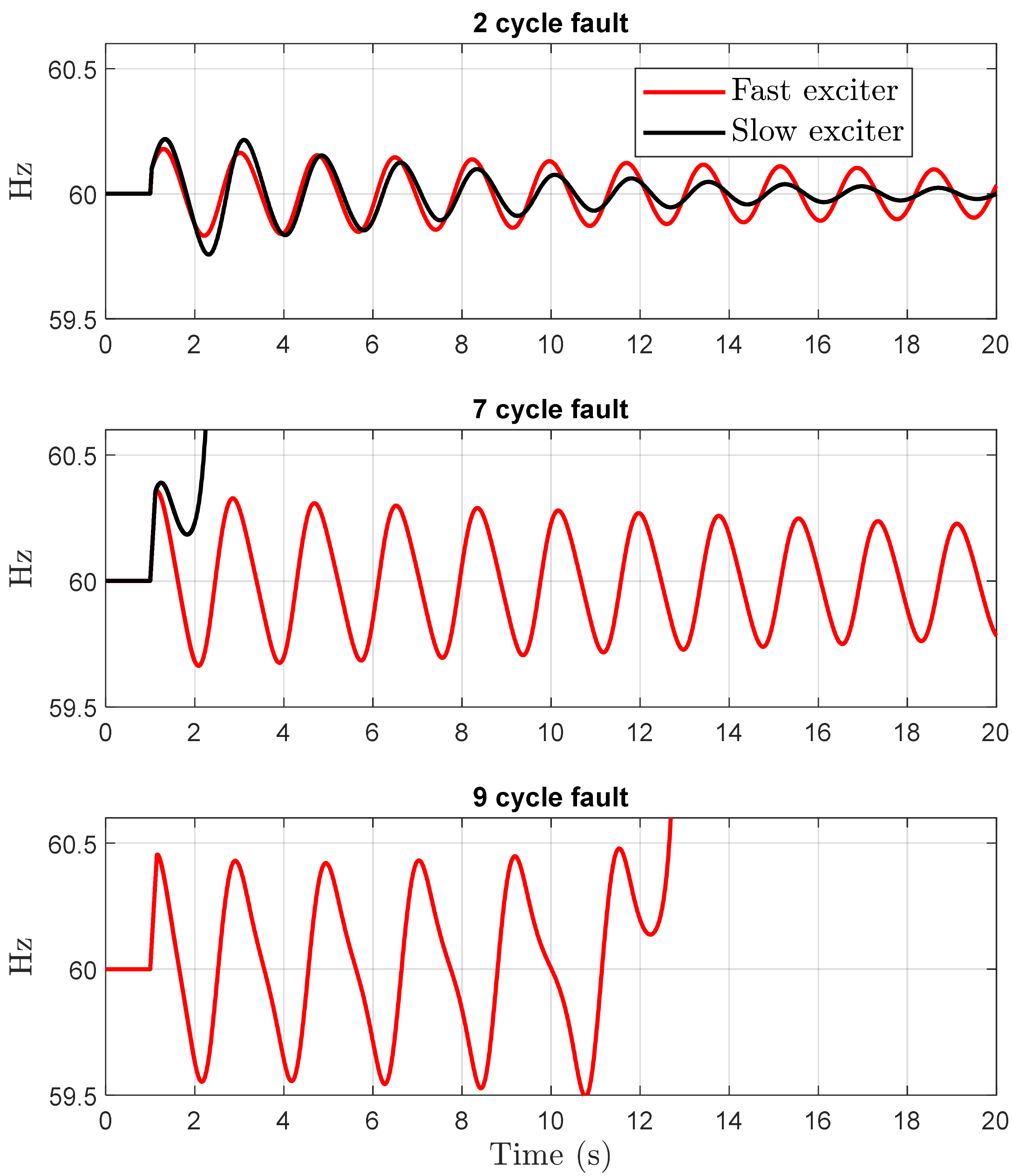
Why did it happen?

Long Transmission w/ Higher Loading



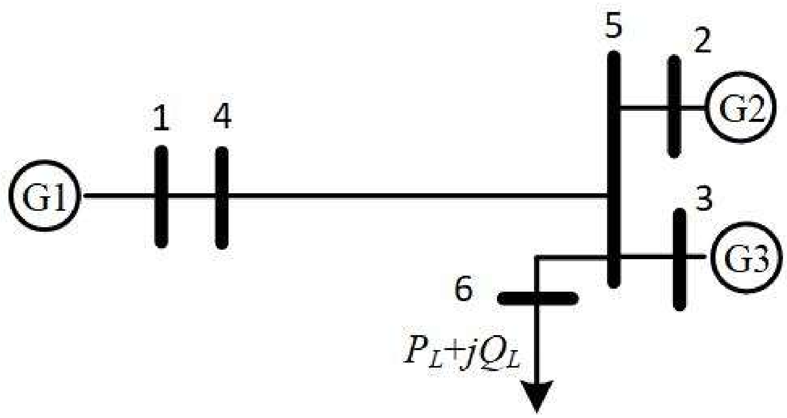


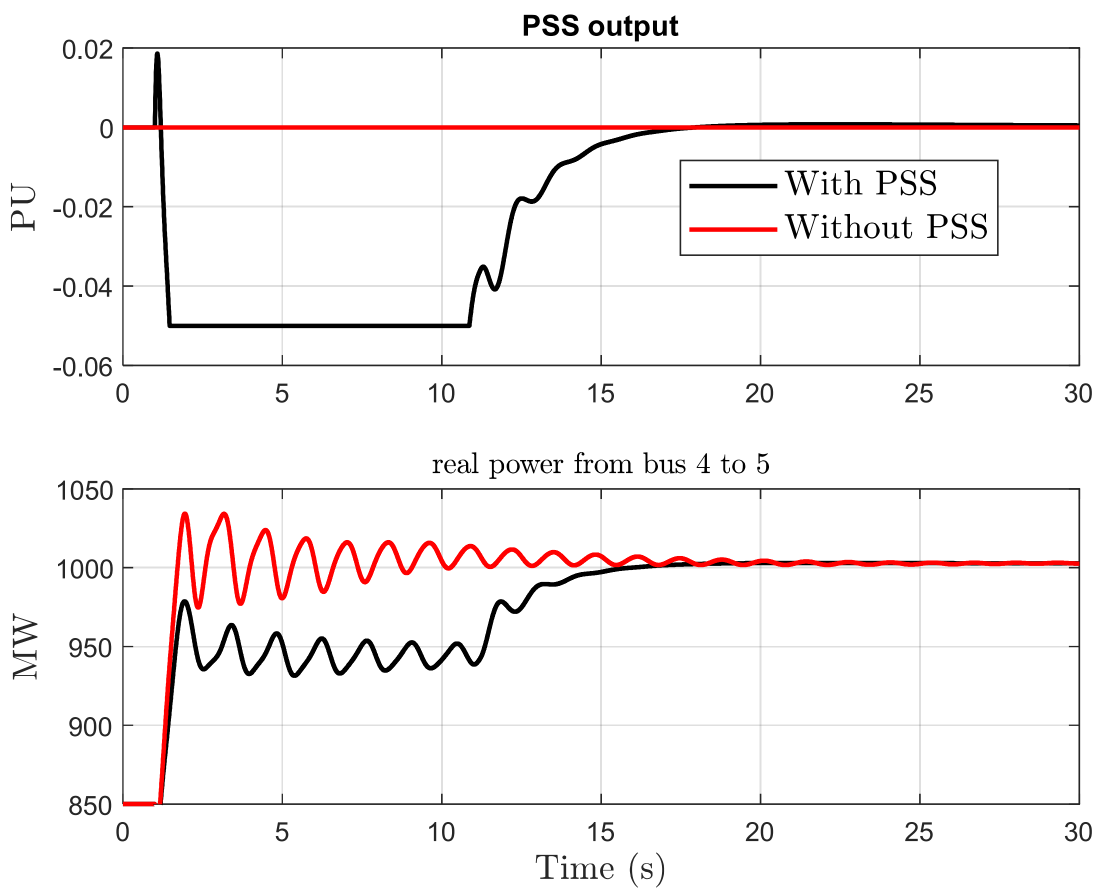
Fast Exciters



- Circa 1980s, slow (DC) exciters were replaced by fast (power electronic) exciters
- The goal was to improve transient stability
- The un-intended consequence was less oscillation damping
- Thus, the PSS was added.

PSS & Excitation Saturation





- PSSs add damping via the excitation
- PSS saturation levels are small (less than 0.1 pu)
- If excitation or PSS limiting occurs, damping is not initiated
- This often occurs when we need it most

Outcomes

Outcomes

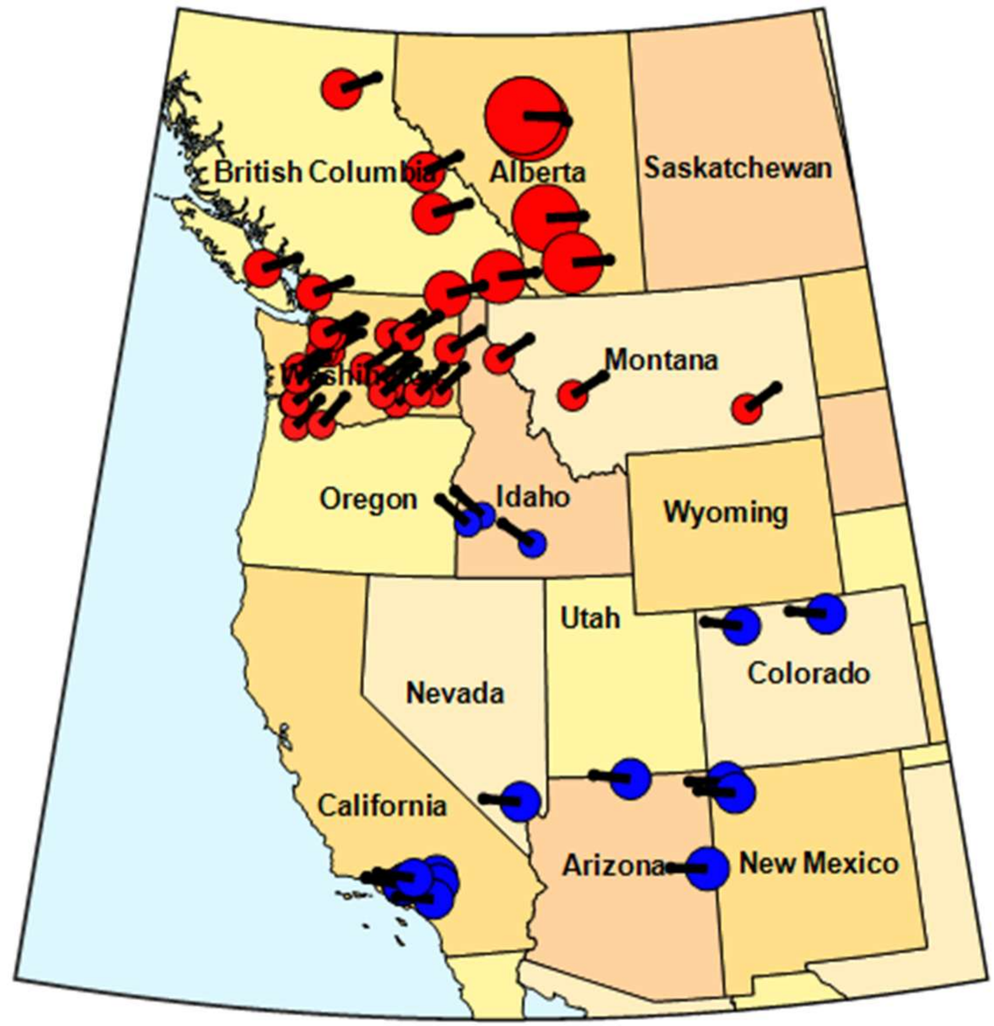
- Dr. John Hauer's WAMS vision came to fruition
  - PMUs and their networks are now common
  - This had significant impacts in understanding the actual system
- Diligence in accurate simulation modeling (e.g., NERC MOD-026-02) and proper control system tuning
- Periodic system testing and modal analysis
  - For the past 2+ decades, BPA routinely conducts PDCI probing and Chief Jo tests to excite the system
  - Enables monitoring of the system modes
- Extensive signal processing research and algorithms for estimating mode parameters
  - Ringdown methods, mode meters, correlation analysis, etc.
- PDCI damping control prototype (2010-2018)
  - Championed by CAISO and BPA.
  - While not operational, much was learned thru the project.
- We now understand WECC modes in great detail!

1996 vs. 2026

Mode	Freq (Hz)	Shape	Controllability	2026	1996
NSA	0.20-0.30	Alberta vs. System	Alberta	An Alberta disconnect causes the NSA mode to disappear	In 1996, we knew there were 2 NS modes. The main hypothesis was the NSA mode was more widespread and troublesome mode.
NSB	0.35-0.45	Alberta vs. (BC + N. USA) vs. S. USA	Widespread, inc. PDCI	The NSB mode is the most widespread and troublesome in the system. An Alberta disconnect causes its frequency and damping to decrease.	
EWA	0.35-0.45	(Colorado + E. Wyo.) vs. System	Colorado area	Close in frequency to the NSB mode.	This mode was unknown in 1996.
BCA	0.50-0.72	BC vs. N. USA vs. S. USA	Unknown	Dominant interarea mode within the BC area. It sometimes ripples to the S. USA.	Little was known about these 2 modes in 1996. There was some research centered in a WSCC working group trying to better understand activity above 0.6 Hz.
MT	0.70-0.90	Montana vs. System	Montana, incl. Colstrip	Sometimes confused with one of the BCA mode.	

North-South A (NSA) Mode

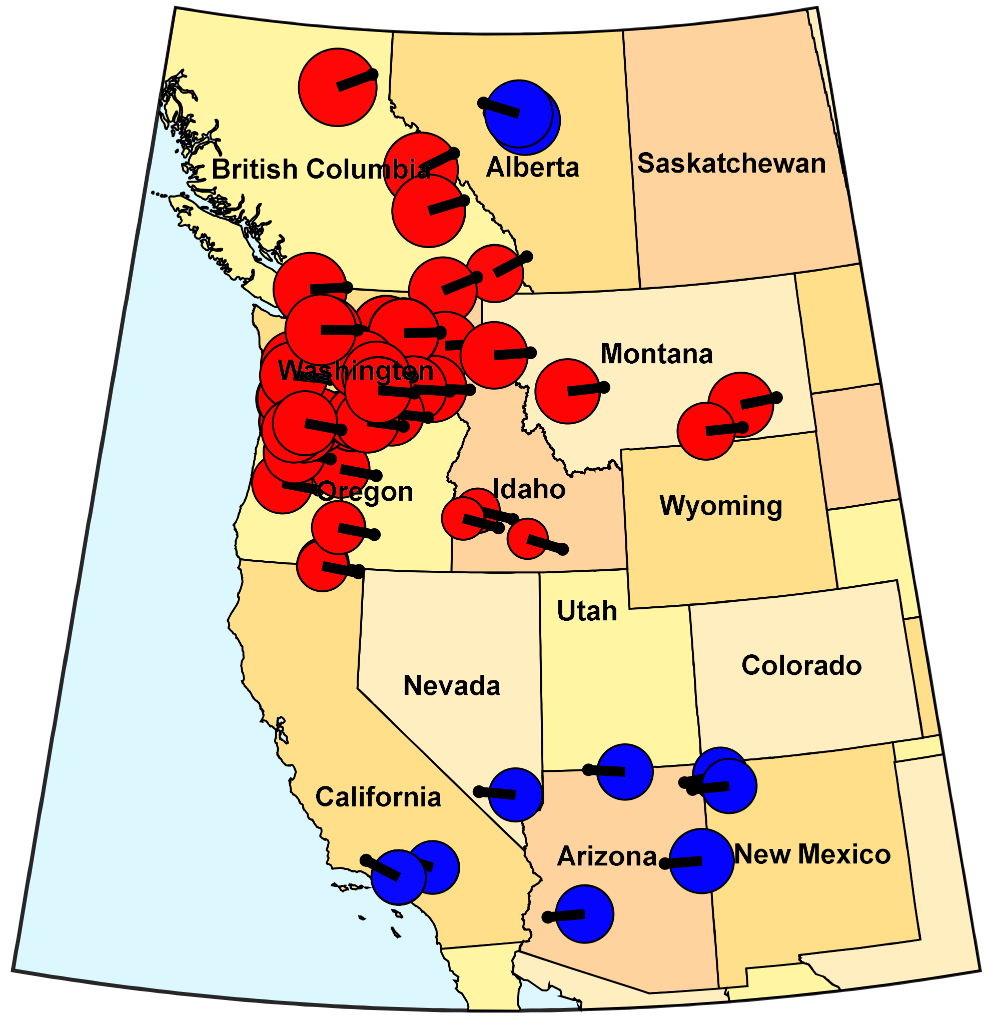
- 0.20 to 0.30 Hz
- Shape—Alberta vs. system
- Disappears when Alberta disconnects



2018

North-South B (NSB) Mode

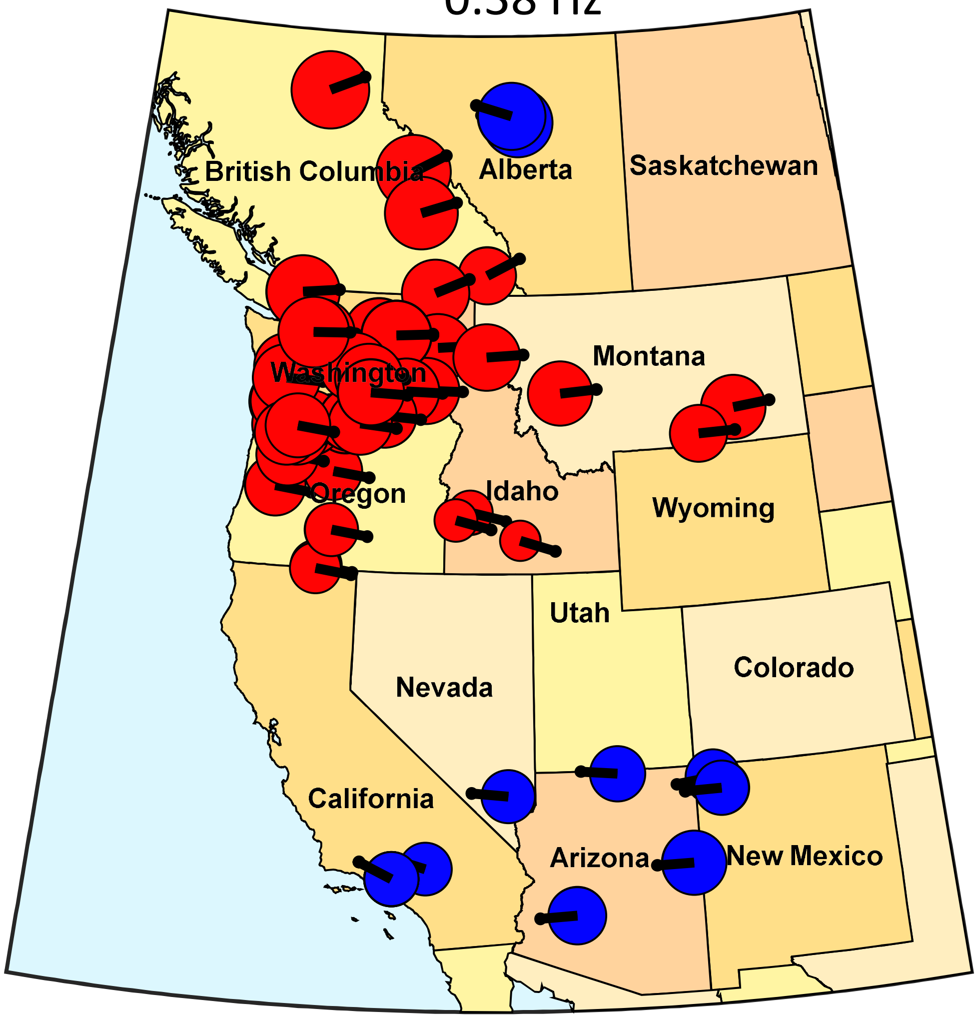
- 0.35 to 0.45 Hz
- Most wide-spread and lightest damped
- Shape—Alberta vs. PNW vs. South
- Alberta disconnect weakens mode
- PDCI controllable



2018

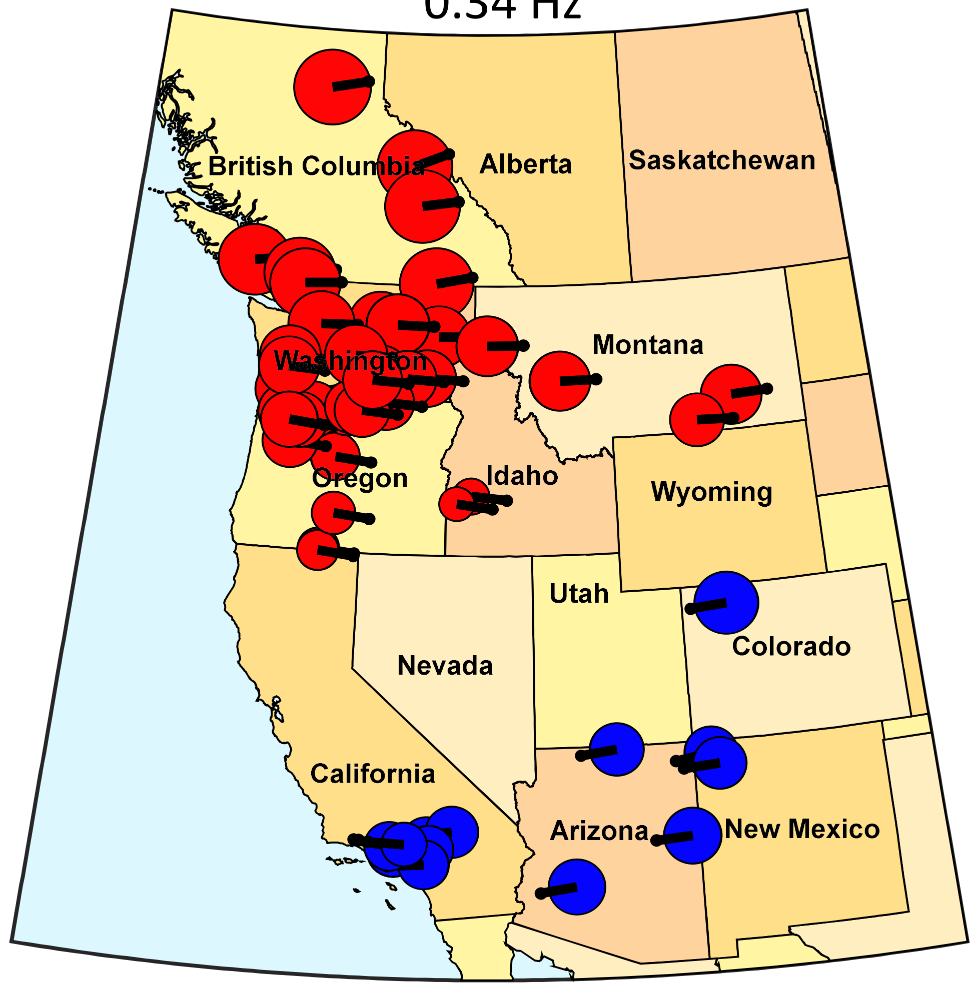
NSB Mode – Alberta Disconnected

Alberta connected
0.38 Hz



2018

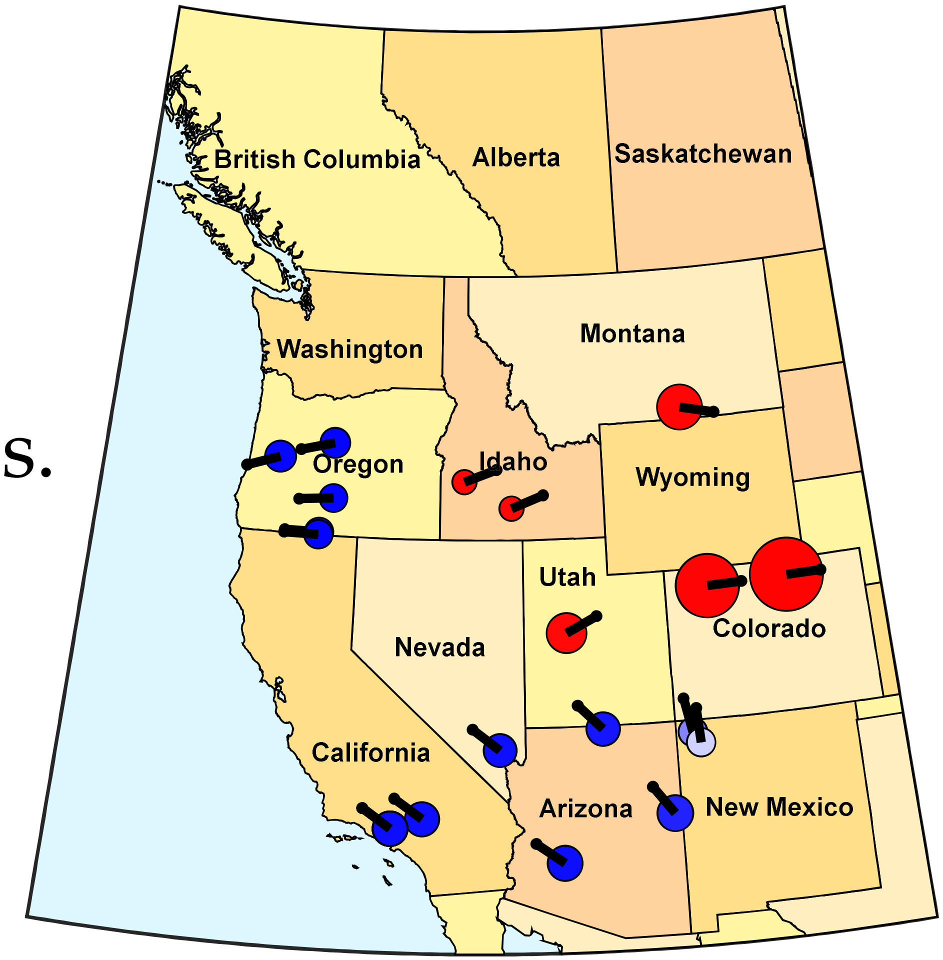
Alberta disconnected
0.34 Hz



2016

East-West A (EWA) Mode

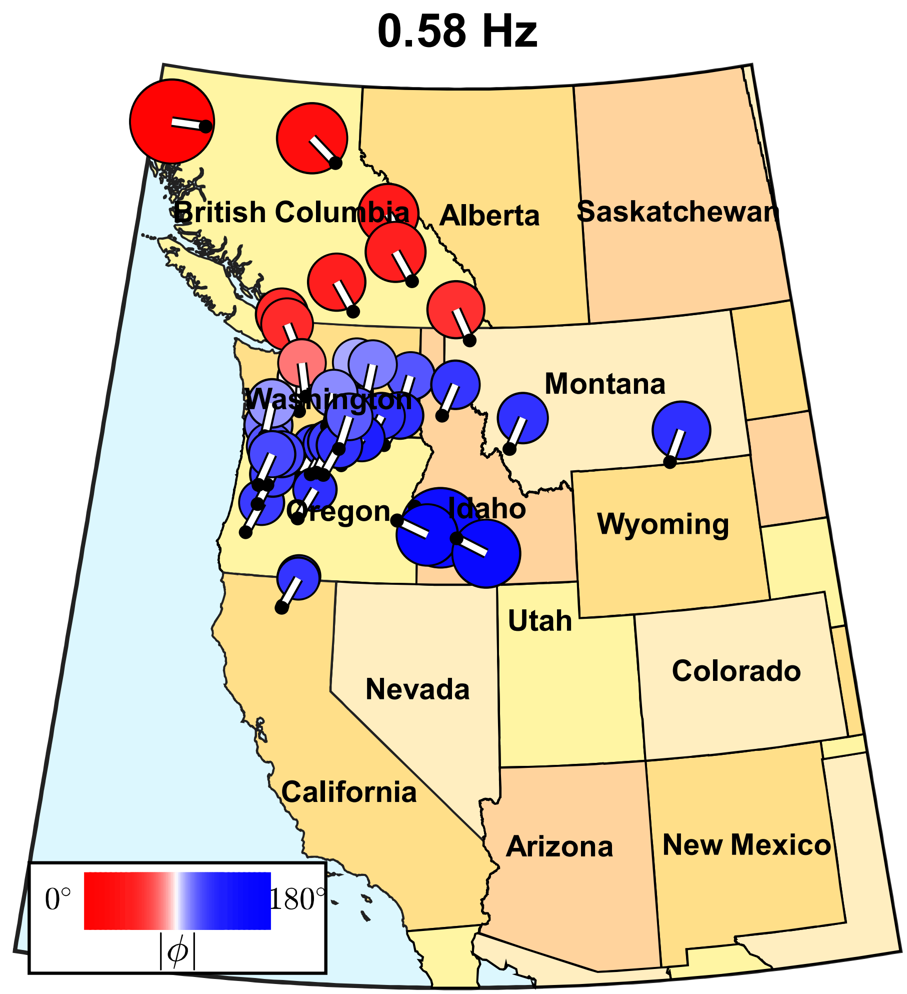
- 0.35 to 0.45 Hz
- Shape—East (Colorado) vs. system



2018

BCA Mode

- 0.50 to 0.70 Hz
- Shape— BC vs NW USA (sometimes ripples to SW USA).



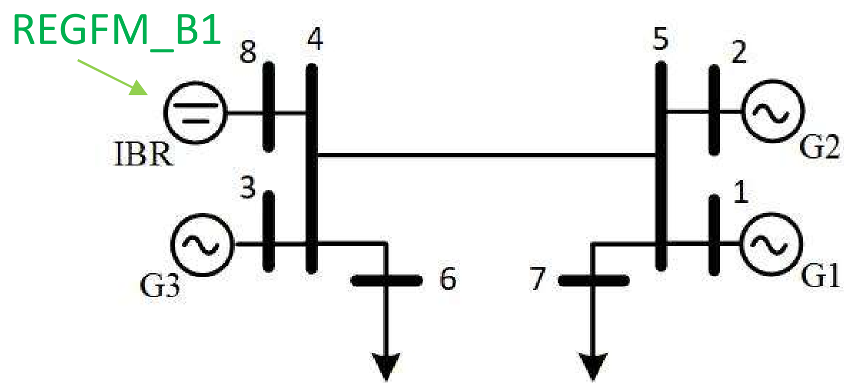
Montana (MT) Mode

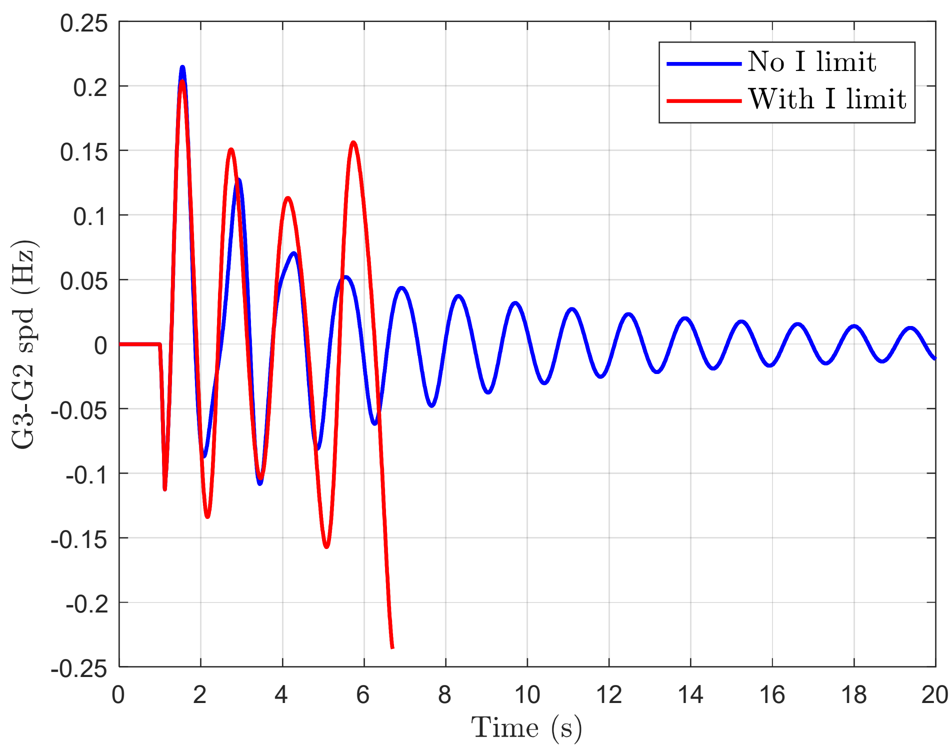
- 0.70 to 0.90 Hz
- Shape—MT vs system.

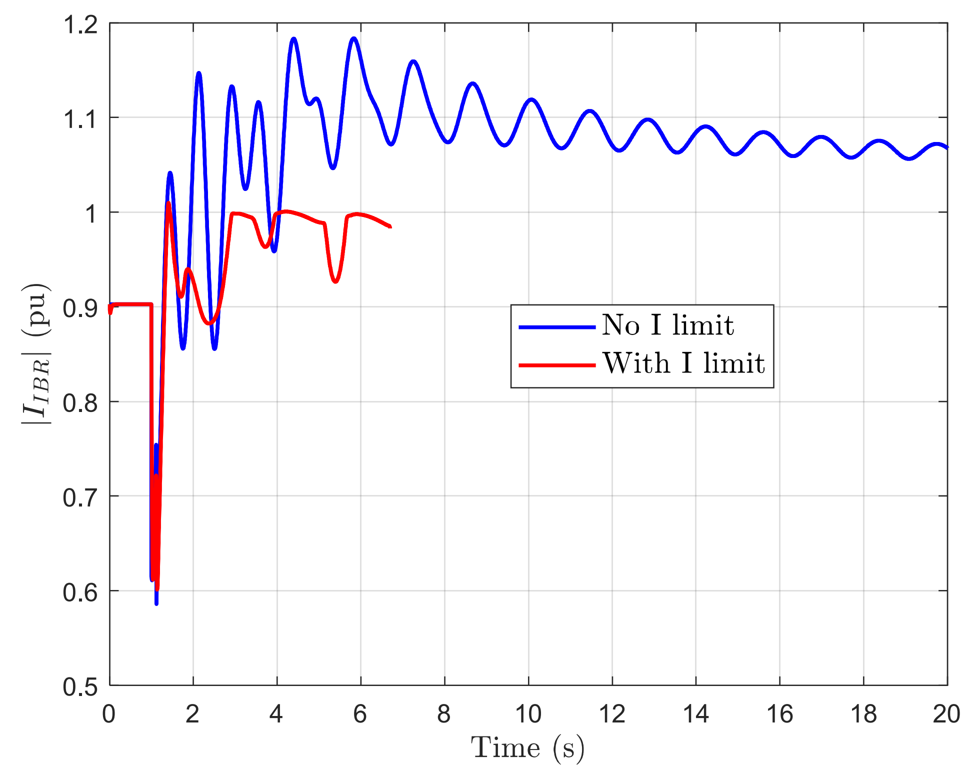
2016

The Future

IBRs Lack Inertial Energy







Concluding Thoughts

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- The 1996 event spurred significant investment, knowledge, and improved engineering!
- It forced us to view the grid as a wide-area dynamic system instead of separate distinct “areas.”
- Monitoring is critical! It must continue.
- Accurate models are critical. We must continue to test and validate our models.
- Wide-area controls buy us margin, but, their impact is limited.
- Large-scale IBRs – they need to truly support the grid.
- Large centralized loads will require specialized RAS and monitoring.