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Solar Small Signal Stability Study

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Agenda

- Project goals
- Project milestones
- Review results from a related FY12 study conducted by Sandia
- Discuss base case options
- Discuss progress to date
- Discussion/feedback from Technical Review Committee

Project Goals

- Assess the effect of high penetration solar deployment on WECC small signal stability
  - Part of overall goal of assessing technical feasibility of high penetration solar deployment in WECC
  - Concurrently, NREL is assessing the effect of high penetration solar deployment on WECC transient stability and frequency stability study
- Employ software that enables full scale simulation of the WECC system and specialized analysis tools
  - Small Signal Analysis Tool (SSAT) developed by Powertech Labs
  - Benchmark against PSLF/Prony results (data analysis in MATLAB)
- Explore sensitivity with respect to key factors (e.g. deployment level, location)

Project Milestones

- 10/12 – Establish TRC
- 01/13 – Establish Base Cases and in consultation with TRC
- 03/13 – Preliminary simulation results and TRC review teleconference
- 06/13 - Summary of results for discussion with TRC
- 07/13 – Draft report For TRC comment
- 09/13 – Final report

- Additional TRC consultation as needed, via email
- TRC members: Vijay Vittal, Dan Trudnowski, Matt Donnelly, Dmitry Kosterev, Juan Sanchez-Gasca, Nick Miller, Kara Clark, Debra Lew

FY2012 WECC Study

- Funded by DOE-Office of Electricity Delivery & Energy Reliability
- Project goals
  - Evaluate WECC small signal and transient stability under high penetrations of wind and solar
  - Evaluate the benefits of control techniques
    - Frequency droop
    - Synthetic inertia
- Study employed three metrics:
  - Mode shape (Prony of generator speeds following a brake insertion)
  - Generator speed with respect to system speed
  - System frequency nadir
- Study focused on high wind penetrations

FY2012 WECC Study

- WECC PSLF test cases – transient and small signal

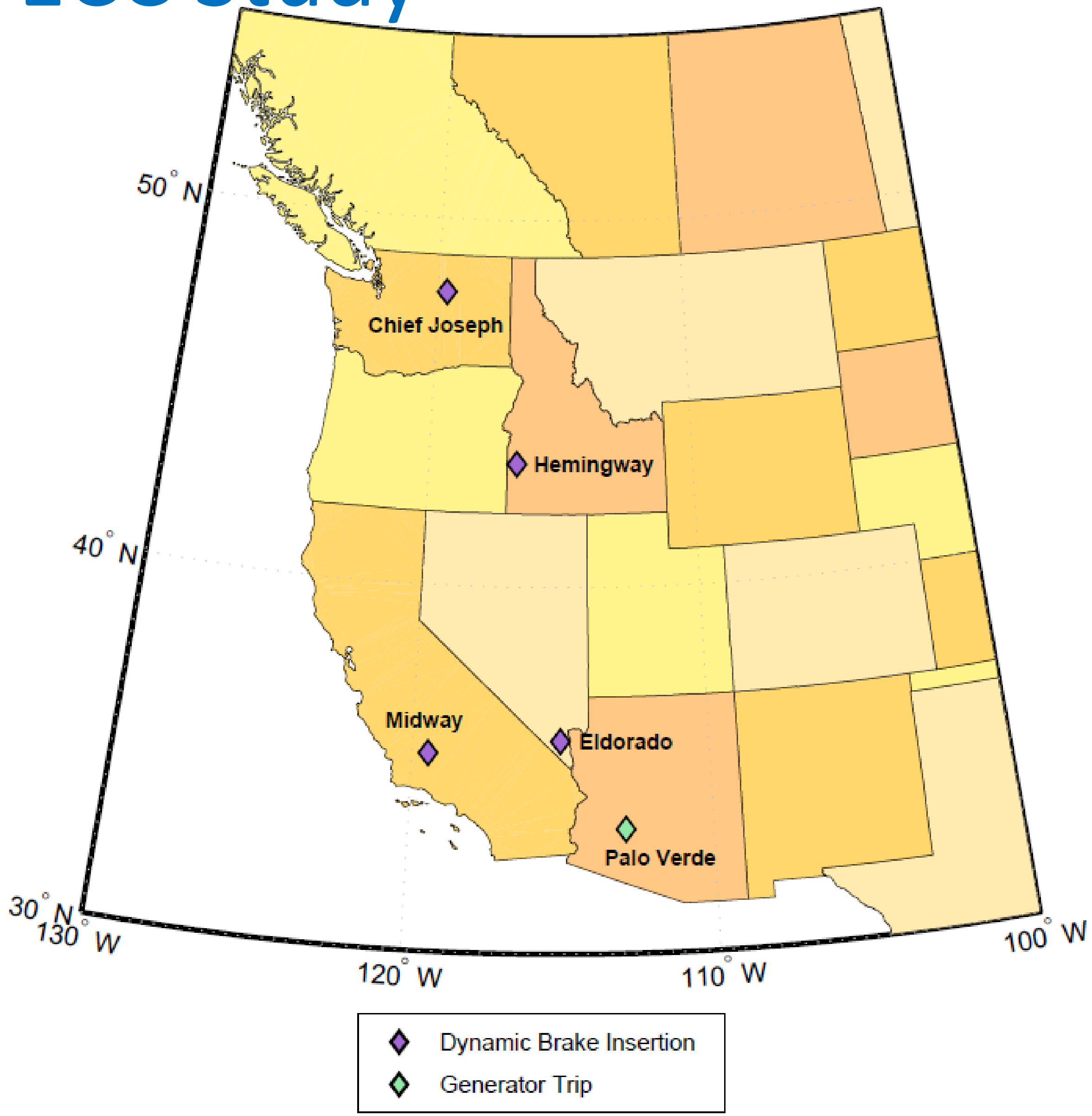
Year	Description	Total Generation (MW)	Renewable Generation (MW)	Percent Renewables (%)
2012	Heavy summer	185,246	1,358	0.73
2012	Heavy winter	147,170	699	0.47
2012	Light summer	120,097	973	0.81
2022	Light spring	120,583	18,124	15.03
2022	Light summer	146,670	10,032	6.84
2022	Heavy winter	182,460	2,276	1.25

- Modified 2022 light spring case
  - All type 3\4 wind plants converted to round rotor generator (genrou)
  - All type 3\4 wind plants converted to genrou, no governor response
  - All wind generation converted to genrou
  - All wind generation converted to genrou, no governor response

FY2012 WECC Study

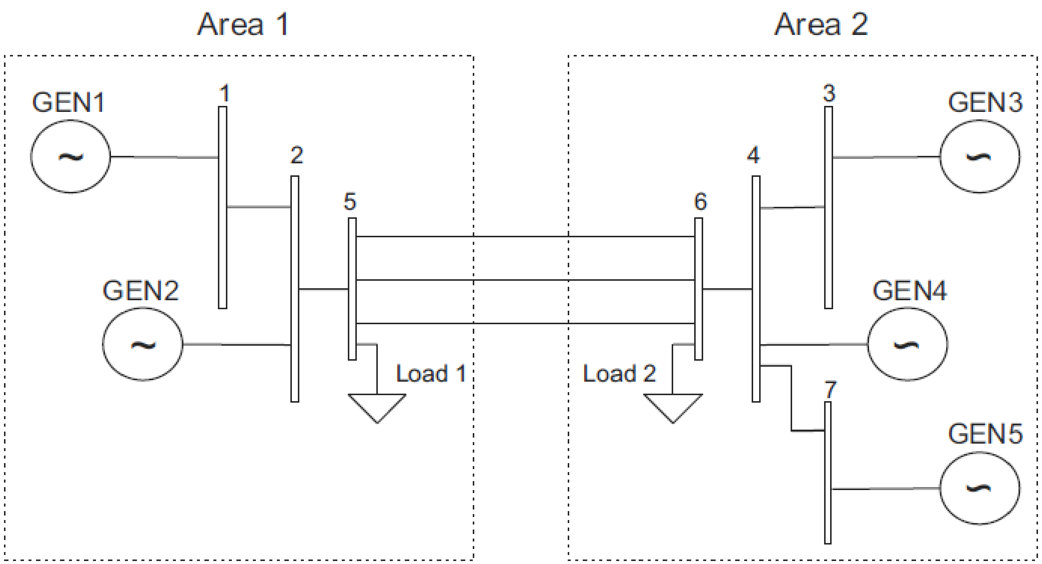
System stimulus:

- Double PV trip
- Chief Joseph dynamic brake insertion



FY2012 WECC Study

- 5-generator, 7-bus system test Cases – transient only



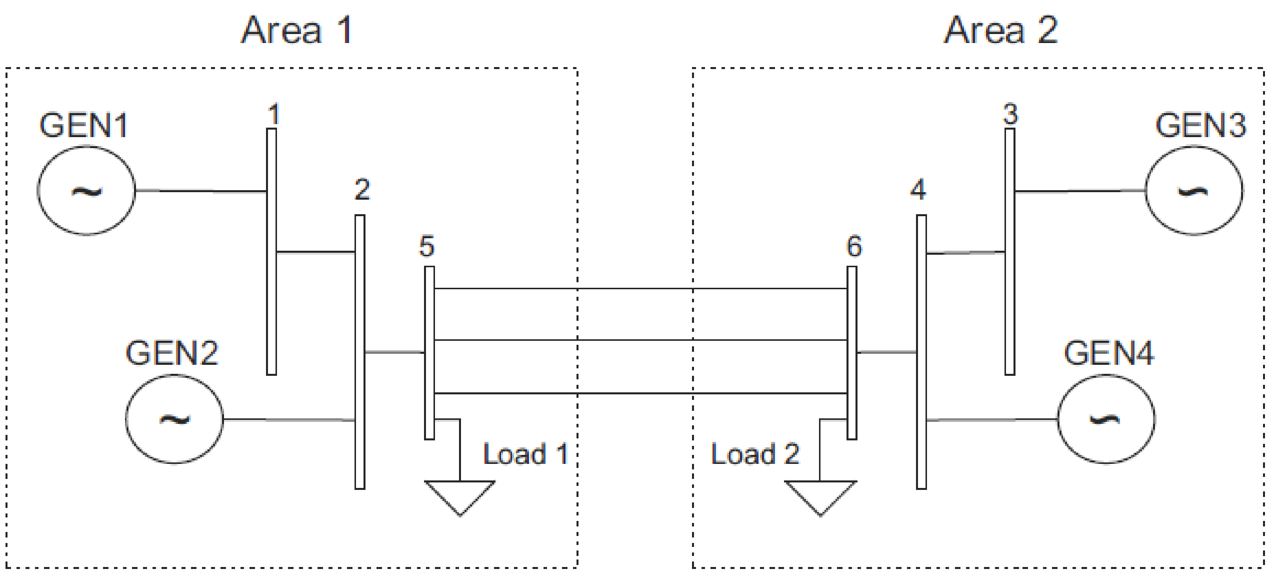
GEN5 tripped at t=10 sec

Name	MVAbase (MVA)	Real Power (t=0) (MW)	Reactive Power (t=0) (MVAr)
GEN1	1000	900	179.5
GEN2	500	400	200
GEN3	900	531	-20.1
GEN4	900	650	423
GEN5	100	50	-50
Load1	NA	1000	250
Load2	NA	1500	250

- Sensitivity to generation type: Generators configured to be all hydro, all coal, or all gas
- Sensitivity to system inertia: Generators configured to be all hydro, all coal, or all gas with inertia varied (± 50%, ± 25%)
- Sensitivity to generation headroom: Generators configured to be all coal, and headroom is reduced by 60% and 80%
- Sensitivity to Wind generation: Generators are first configured to be all hydro, all coal, or all gas; then GEN3 is adjusted for loss of governor control and a change to wind generation with and without additional power compensation (e.g. frequency droop and synthetic inertia)

FY2012 WECC Study

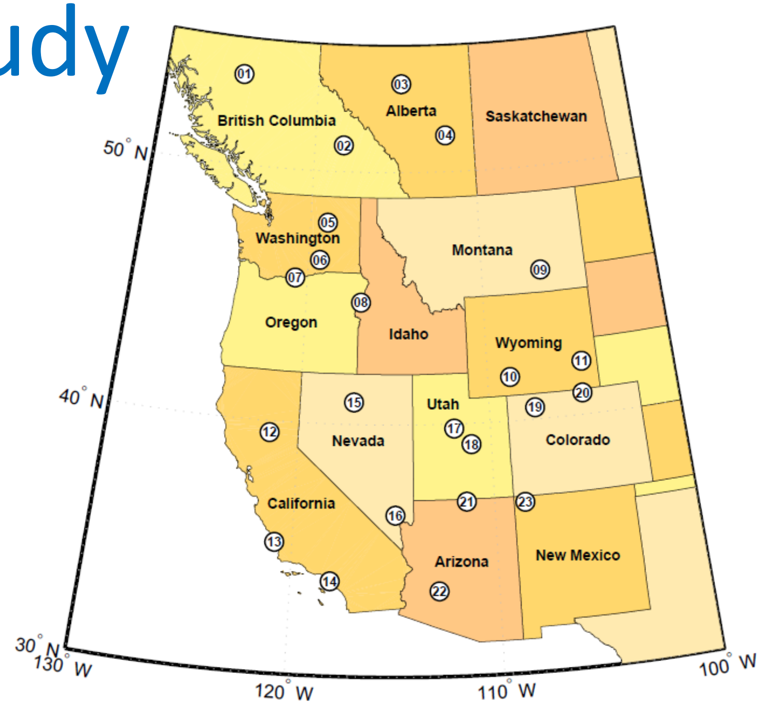
- 4-generator, 6-bus system test cases – small signal only



- Fault on bus 5
- GEN3 replaced with a type 4 wind plant
- GEN3 replaced with a type 4 wind plant with frequency droop
- GEN3 replaced with a type 4 wind plant with inertial emulation (local storage)

FY2012 WECC Study

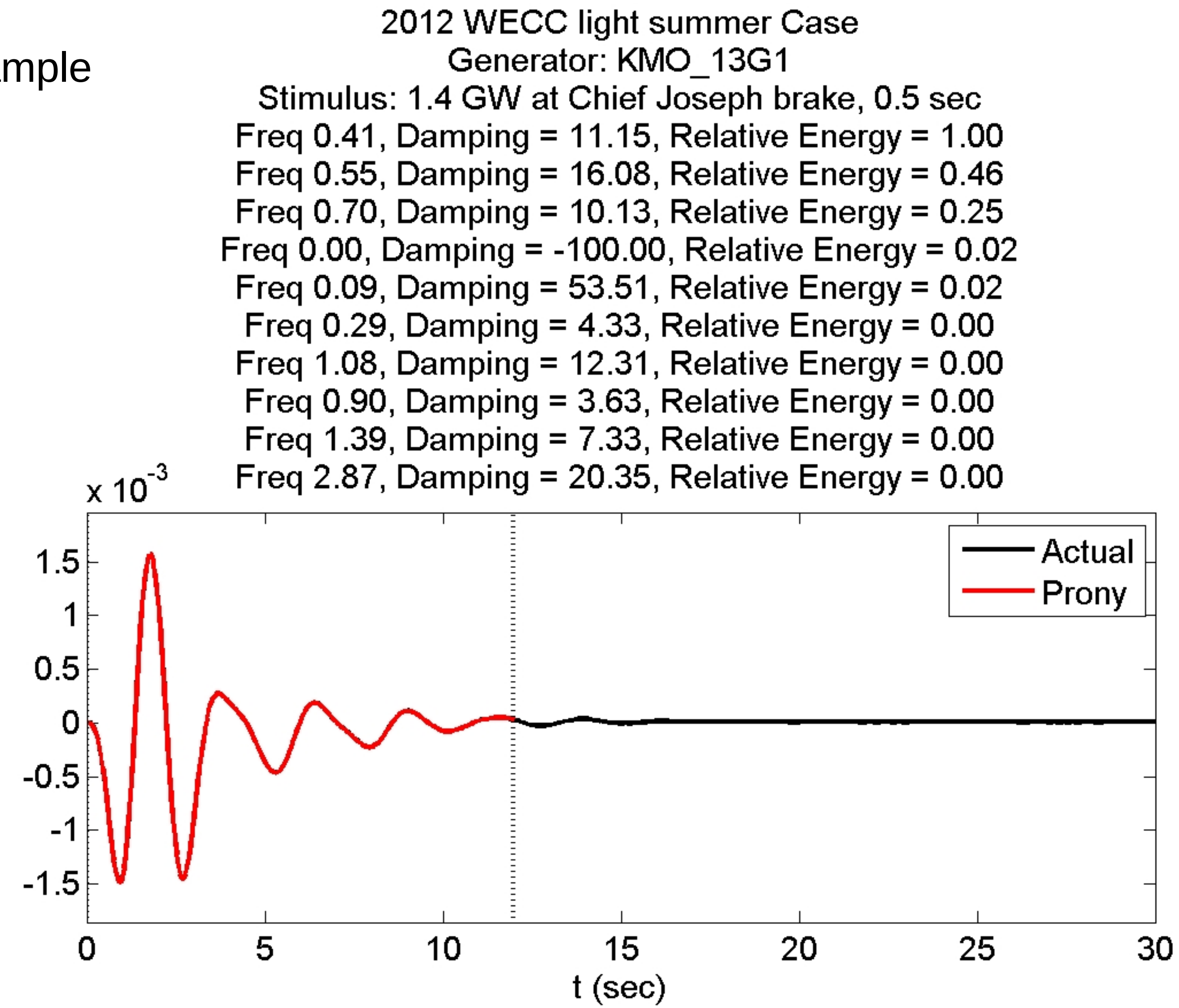
Monitored generators



Marker Number	Plant Name	Marker Number	Plant Name
01	Kemano Power Station	13	Diablo Canyon Power Plant
02	Revelstoke Dam	14	Haynes Generating Station
03	Sundance Power Plant	15	North Valmy Generating Station
04	Sheerness Generating Station	16	Silverhawk Generating Station
05	Grand Coulee Dam	17	Currant Creek Power Plant
06	Columbia Generating Station	18	Hunter Power Plant
07	John Day Dam	19	Craig Generating Station
08	Brownlee Dam	20	Rawhide Energy Station
09	Colstrip Power Plant	21	Navajo Generating Station
10	Jim Bridger Power Plant	22	Palo Verde Generating Station
11	Laramie River Generating Station	23	San Juan Generating Station
12	Edward Hyatt Power Plant		

FY2012 WECC Study

Ring down example

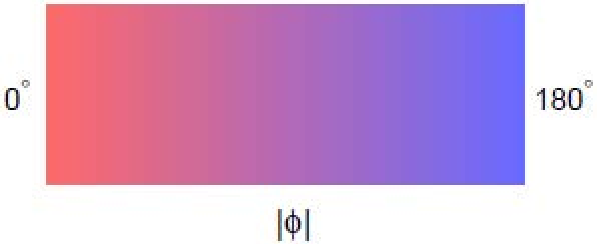


FY2012 WECC Study

- With default configuration, type 3\4 wind plants do not participate in inter-area oscillatory stability
  - Decoupling between drivetrain and the grid
  - Control interactions (not inter-area modes) are possible
- However, there could be an impact due to
  - change in inertia distribution
  - change in power flow patterns
  - reduced governor response

FY2012 WECC Study

Sample mode shape map



Relationship between marker color and residue angle

Marker size is proportional to the magnitude of the residue

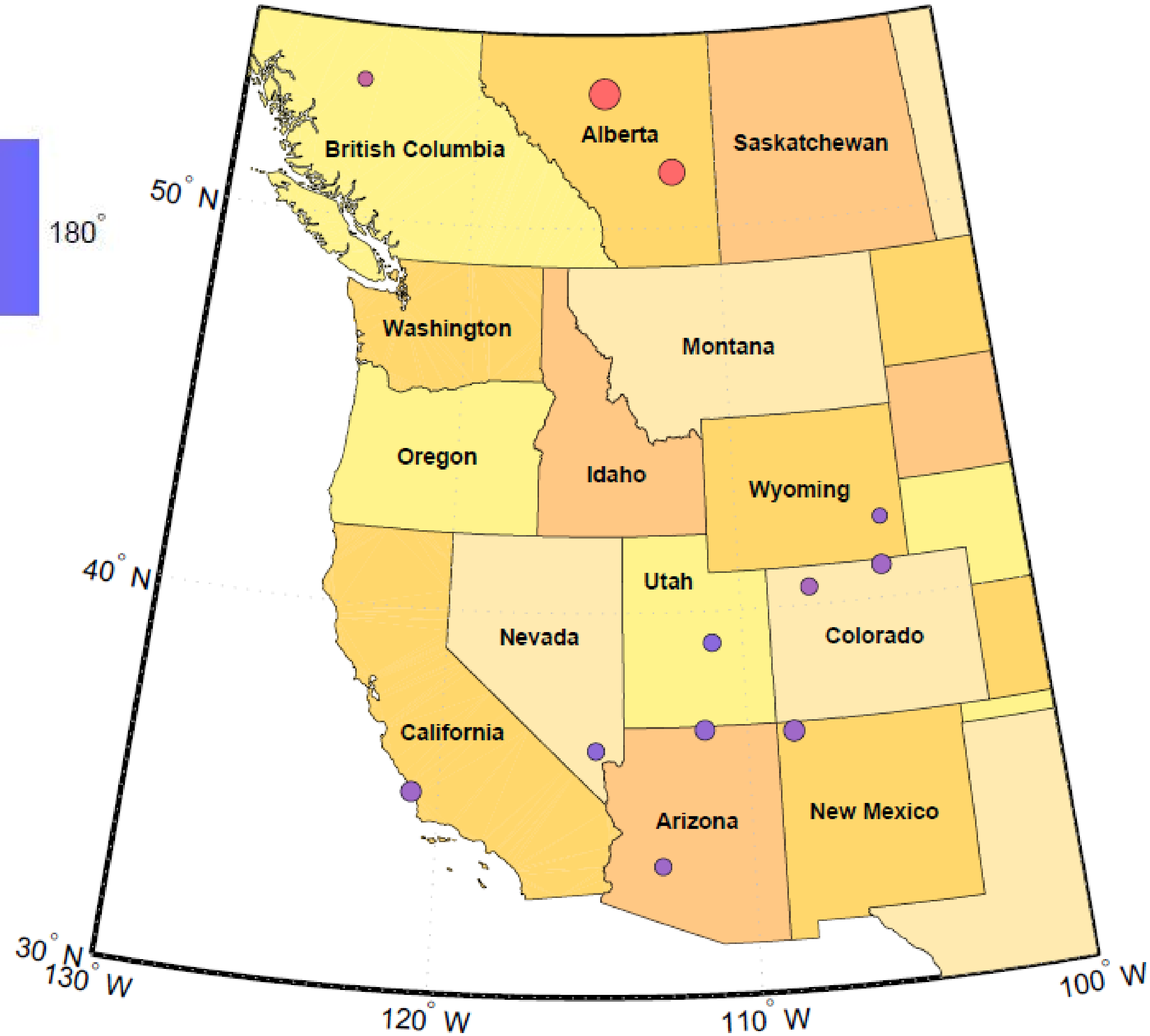


Figure 30: 2012 heavy winter, 0.24 Hz inter-area oscillation mode.

FY2012 Study

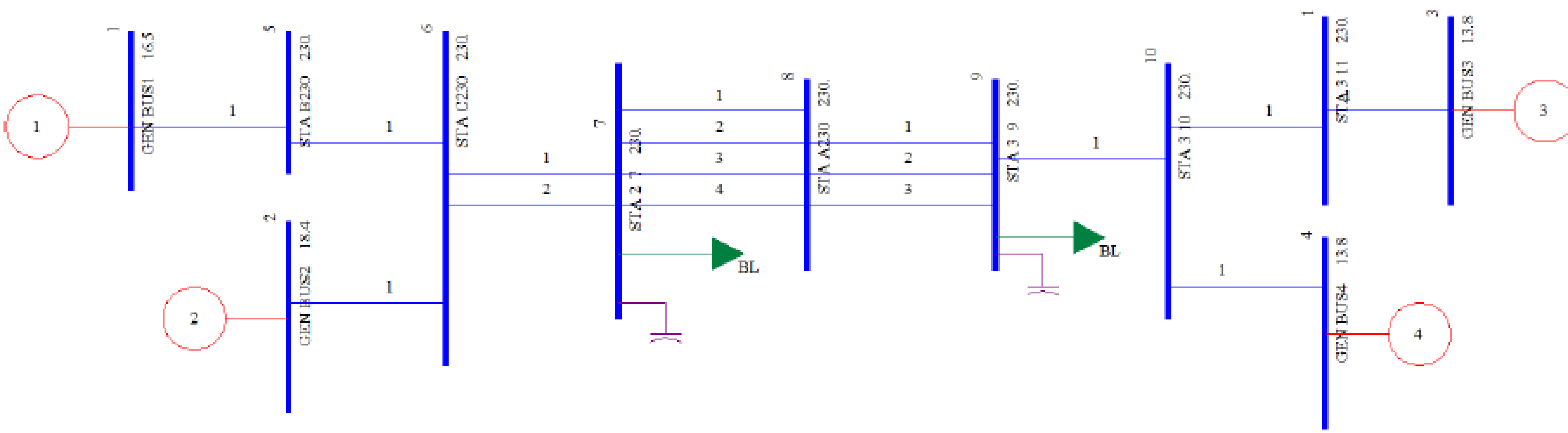
- Lessons learned
  - Difficult to interpret the results for different WECC base cases because so many variables change (e.g. load, power flows, dispatch, etc.)
  - Isolating the changes (e.g. increased wind penetration) so that only one factor changes at a time helps
    - Small system
    - WECC case with one change, e.g. replace wind with genrou
  - Modifying a WECC base case can be difficult
    - Need to consider economic dispatch, transmission constraints, etc.
    - Do the modifications match the expected reality?

Solar Small Signal Stability Study

- Proposed methodology
  - Start with the 2022 light spring and 2022 heavy winter WECC base cases
  - Verify the accuracy of the model with respect to wind/solar penetration
  - Develop several variants of the base case with differing renewable penetration
    - Keep power flows the same
    - Substitute generation at the same location
  - Import the models into SSAT
  - Perform the analysis
  - Perform additional analysis with simple models to verify findings as needed
  - Perform Prony analyses using PSLF simulations to validate results in SSAT

Progress to date

- Coming up to speed on SSAT
- Comparison of results from SSAT and PSLF for simple system



Progress to Date

Table 1: QR algorithm and Prony analysis results comparison

Intact System - No Contingency				
	Mode 1 frequency (Hz)	Mode 1 damping (%)	Mode 2 frequency (Hz)	Mode 2 damping (%)
QR	0.802	5.445	0.172	53.905
Prony	0.797	6.993	0.193	44.604
Prony stdv	0.001	0.056	0.001	0.734

Line Outage - Bus 7 to Bus 8				
	Mode 1 frequency (Hz)	Mode 1 damping (%)	Mode 2 frequency (Hz)	Mode 2 damping (%)
QR	0.785	5.397	0.171	54.433
Prony	0.780	7.285	0.205	40.162
Prony stdv	0.004	0.436	0.004	3.696

Potential Roadblocks

- For the PSLF cases, we need to quantify the number of models that are not imported by SSAT and determine the need to develop custom models
  - User-written models in the PSLF case (e.g., PDCI)
  - Wind and solar models and default data
- SSAT does not provide an indication of “relative response” as a result of some stimulus (Prony does). This can be calculated offline if we can export the linearized system from SSAT.

Concluding Remarks

- Feedback from and discussion with the TRC
- Next TRC meeting in ~2 months