Peak's Tools and Practice for Western System Oscillation Monitoring and Source Locating

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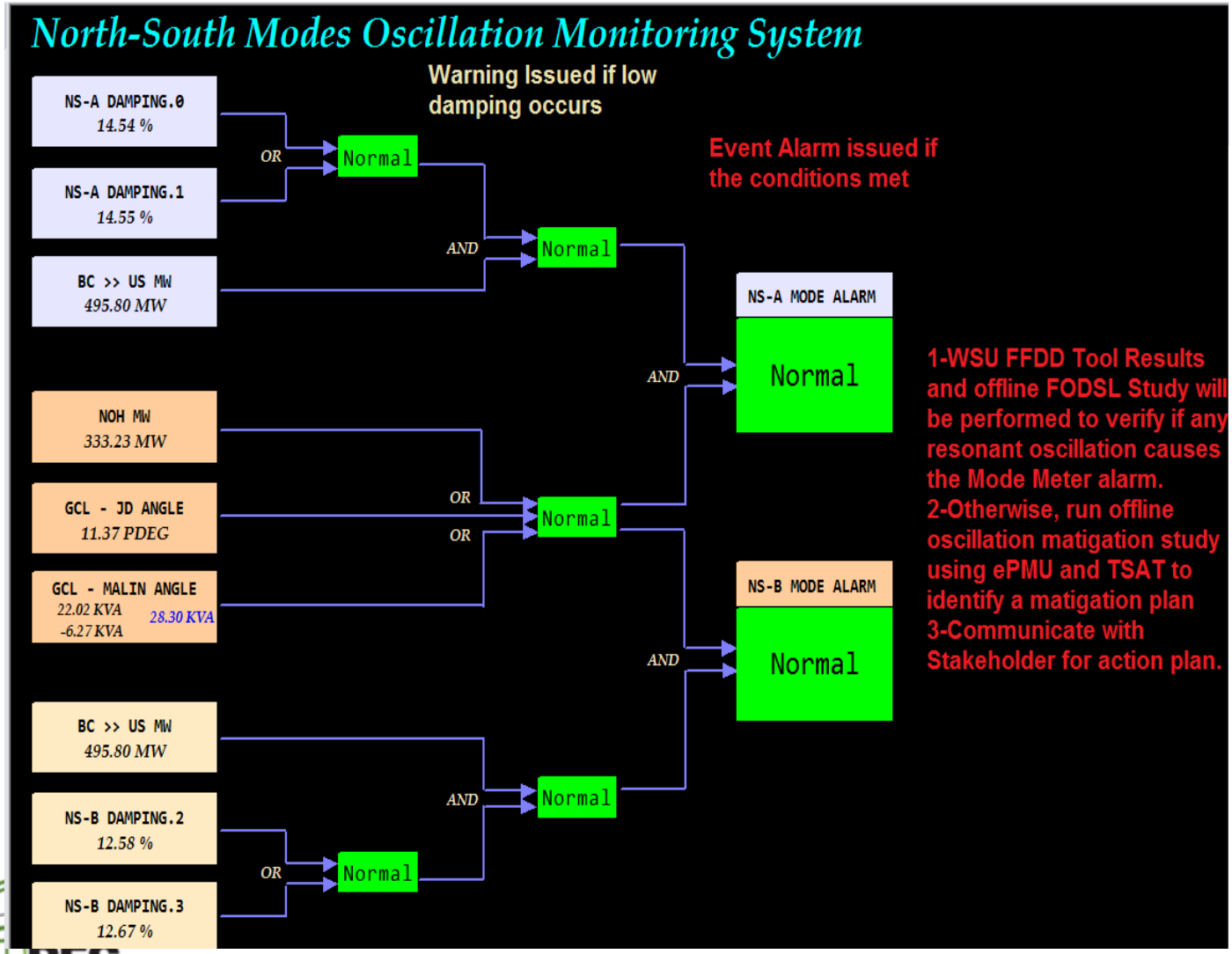
Agenda

- Introduction: Tools and Use Cases
  - MontanaTech's MAS/Mode Meter
  - Washington State Univ.(WSU) Oscillation Tools
- Oscillation Events and Study Cases
  - Forced Oscillation Events
  - BC Mode Low Damping Case Study
  - TSAT Simulation on August 1996 Blackout events
- Conclusion

Peak's Oscillation Monitoring Tools

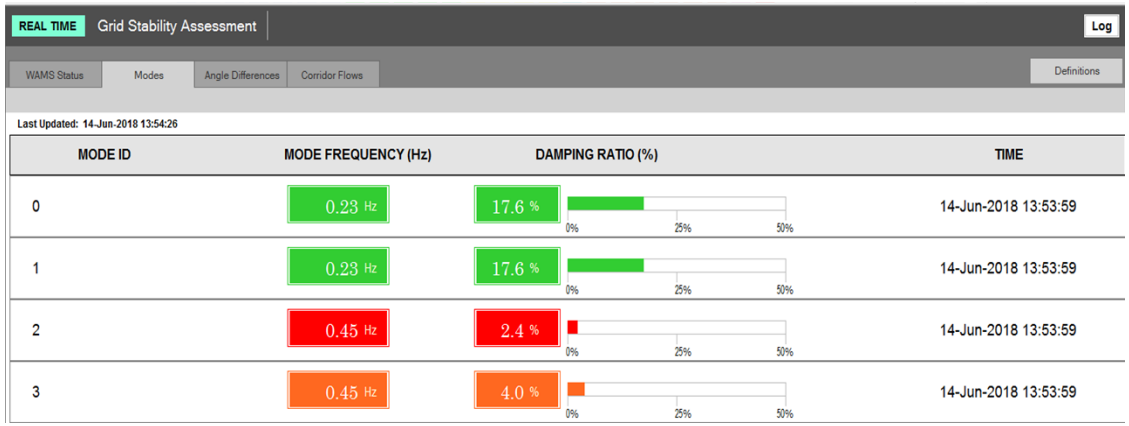
- MAS/Mode Meter is running to calculate 5 inter-area system oscillation modes in every 10s
- Implement low damping alarms on North-Source Modes similarly as BPA does for validation test
- Deploy WSU real-time forced oscillation detection and source locating tool (FODSL) in Test servers
- Install stand alone SL tool in Prod for offline study
- Review real-time FODSL and Mode Meter results weekly and report new findings with entities

North-South Modes Monitoring

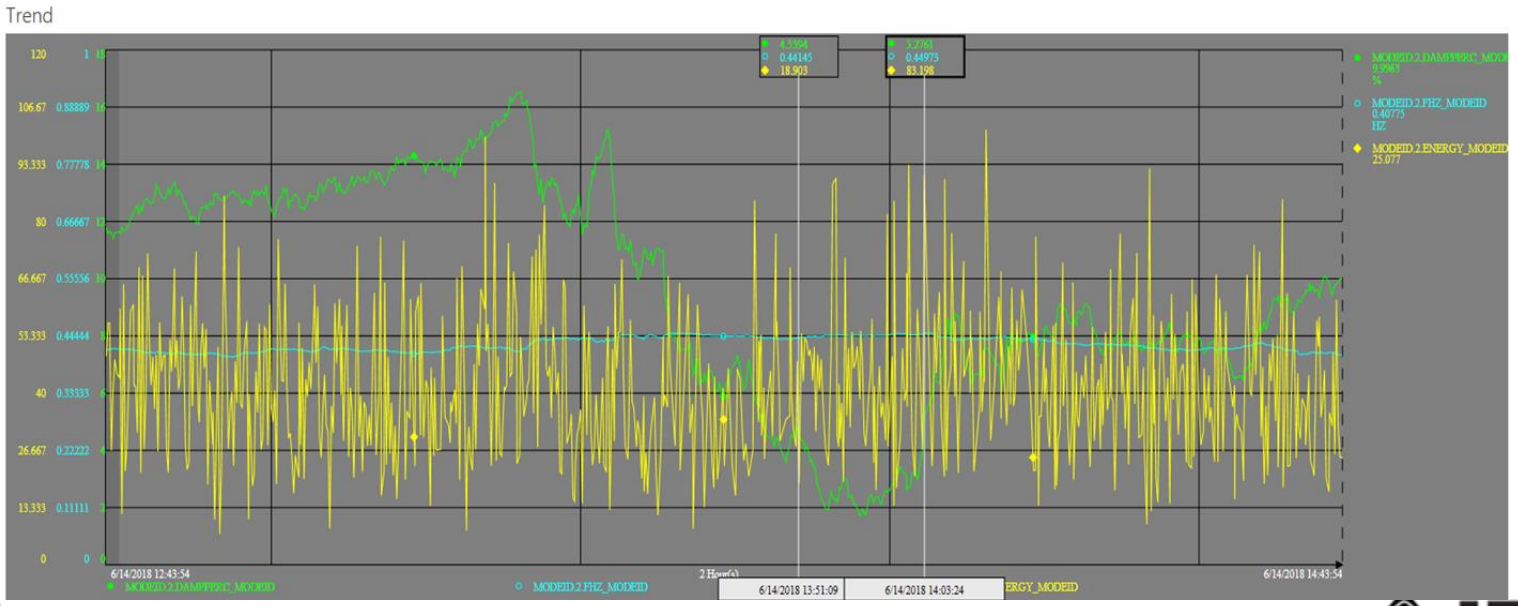


1. **Low Damping Alarmed if**
   1-A. NS-A <7%
   1-B. NS-B <4%
2. **System Oscillation Alarmed if all conditions are met**
3. **Alarms sent to NetApps team only for validation**
4. **No system oscillation alarm found since last Oct**

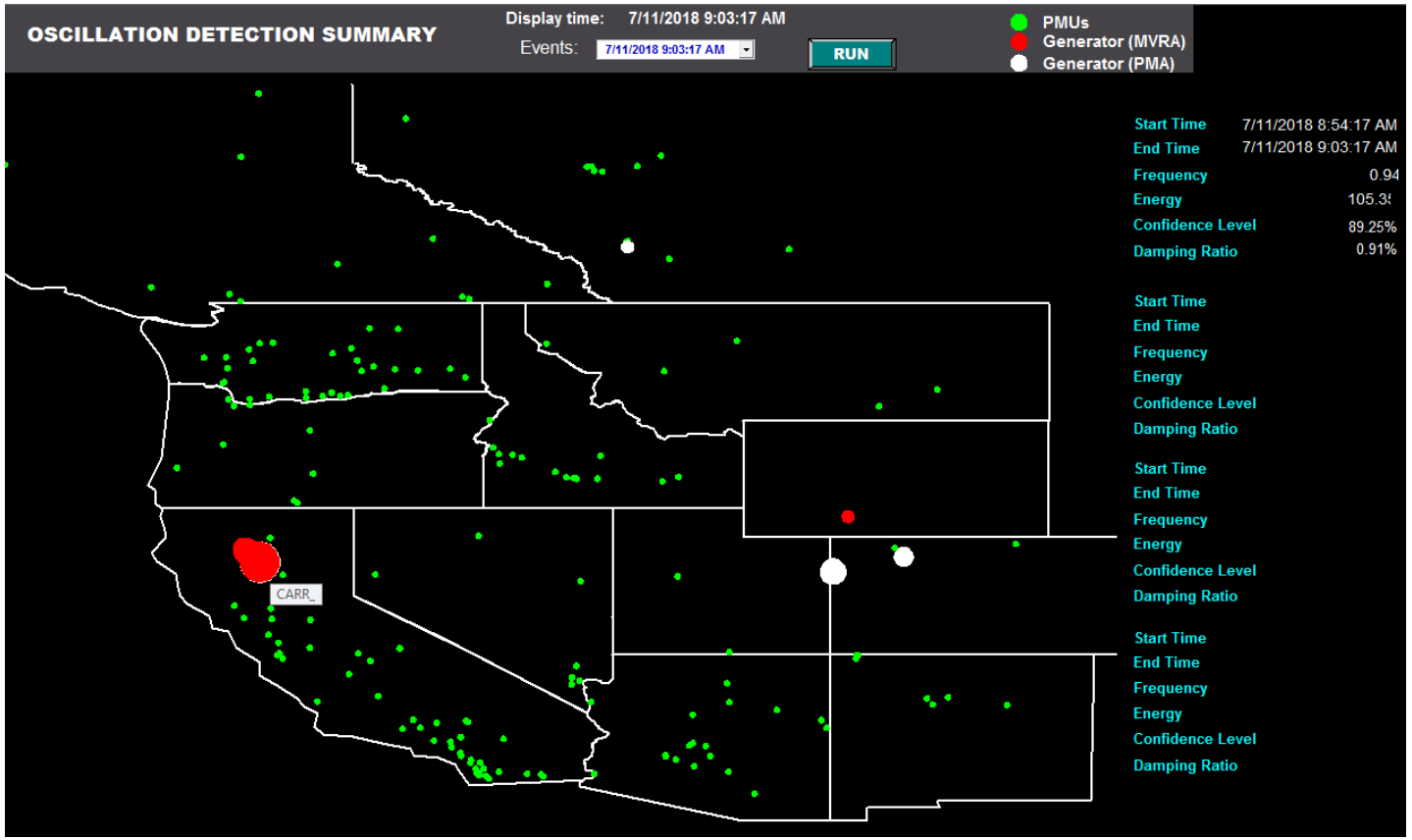
Mode Meter Results on a Event



An exemplary case: Mode Meter (the solution results integrated in EMS and PI) correctly detected low damping on N-S mode B during BPA PDCI probe test on May 23 2018

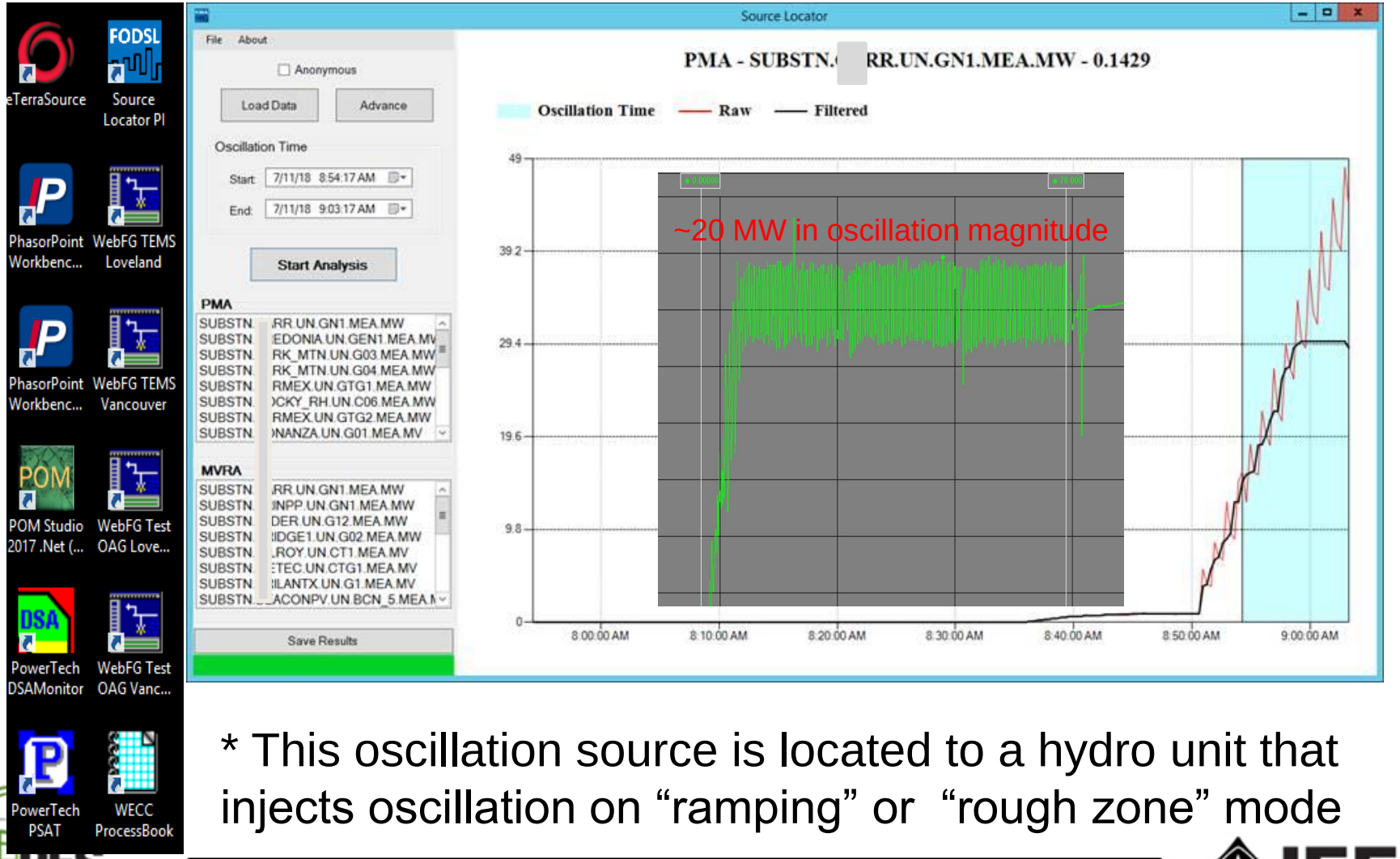


RT-FODSL Tool UI and Use Cases



FODSL tool can identify and display (1) multiple oscillation modes; (2) top oscillation source candidates; (3) selected mode shapes.

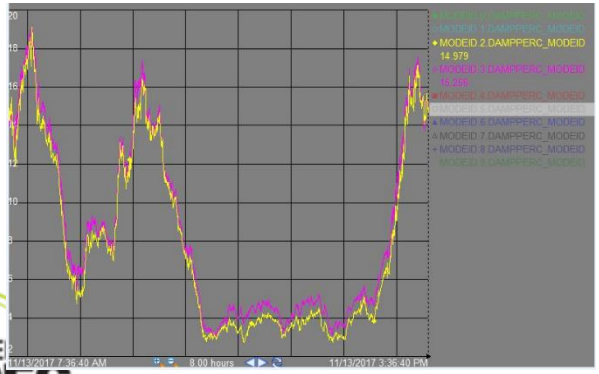
Offline Source Locating Study Case

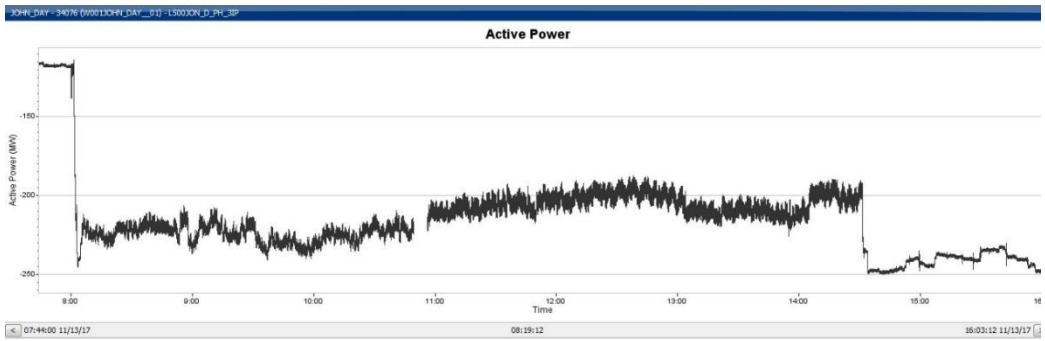


* This oscillation source is located to a hydro unit that injects oscillation on “ramping” or “rough zone” mode

Oscillation Events by FODSL

- **8/31/2017 1.23 Hz** Forced Oscillation (lasting for 6 hours) found at a hydro plant
- **11/13/2017 0.4 Hz** (NS-Mode B) Oscillation showed low damping for 6.5 hours
  - FODSL identified the unit that generated biased input signals and caused Mode B false alarm

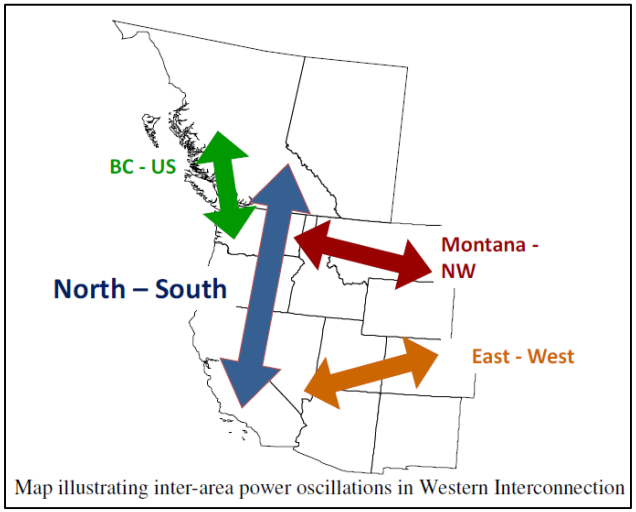




British Columbia (BC) Mode Study

- BC Mode refers to the generation in British Columbia is oscillating against Pacific Northwest. The frequency is 0.55 ~ 0.6Hz
- BC Mode shows most low damping issues

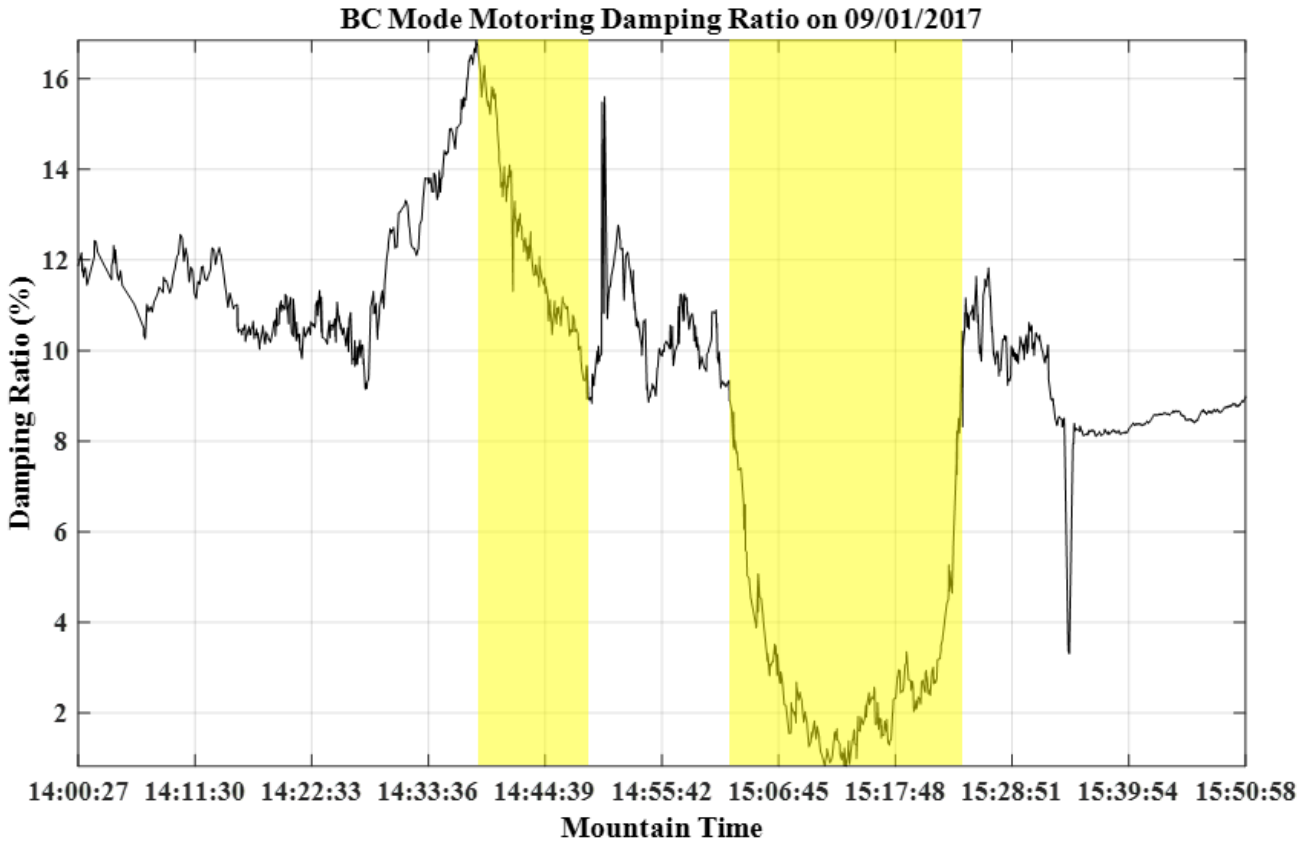
System Modes	Total Good data Count	Below 5%	(5%) % of the Total Count	Below 3%	(3%) % of the Total Count
NS-Mode A Primary	798670	234	0.03%	0	0.00%
NS-Mode A Secondary	798687	238	0.03%	0	0.00%
NS-Mode B Primary	879415	1497	0.17%	129	0.01%
NS-Mode B Secondary	877476	1406	0.16%	2	0.00%
Montana Mode Primary	858157	19886	2.32%	5948	0.69%
Montana Mode Secondary	628933	12476	1.98%	3869	0.62%
British Columbia Mode	729285	66024	9.05%	28481	3.91%
Mode7 (Bad Signal)	292760	1155	0.39%	483	0.16%
E-W Mode Primary	731173	10454	1.43%	2947	0.40%
E-W Mode Secondary	725993	18024	2.48%	5741	0.79%



Map illustrating inter-area power oscillations in Western Interconnection

* Study Statistics data (08/21/2017-11/30/2017)

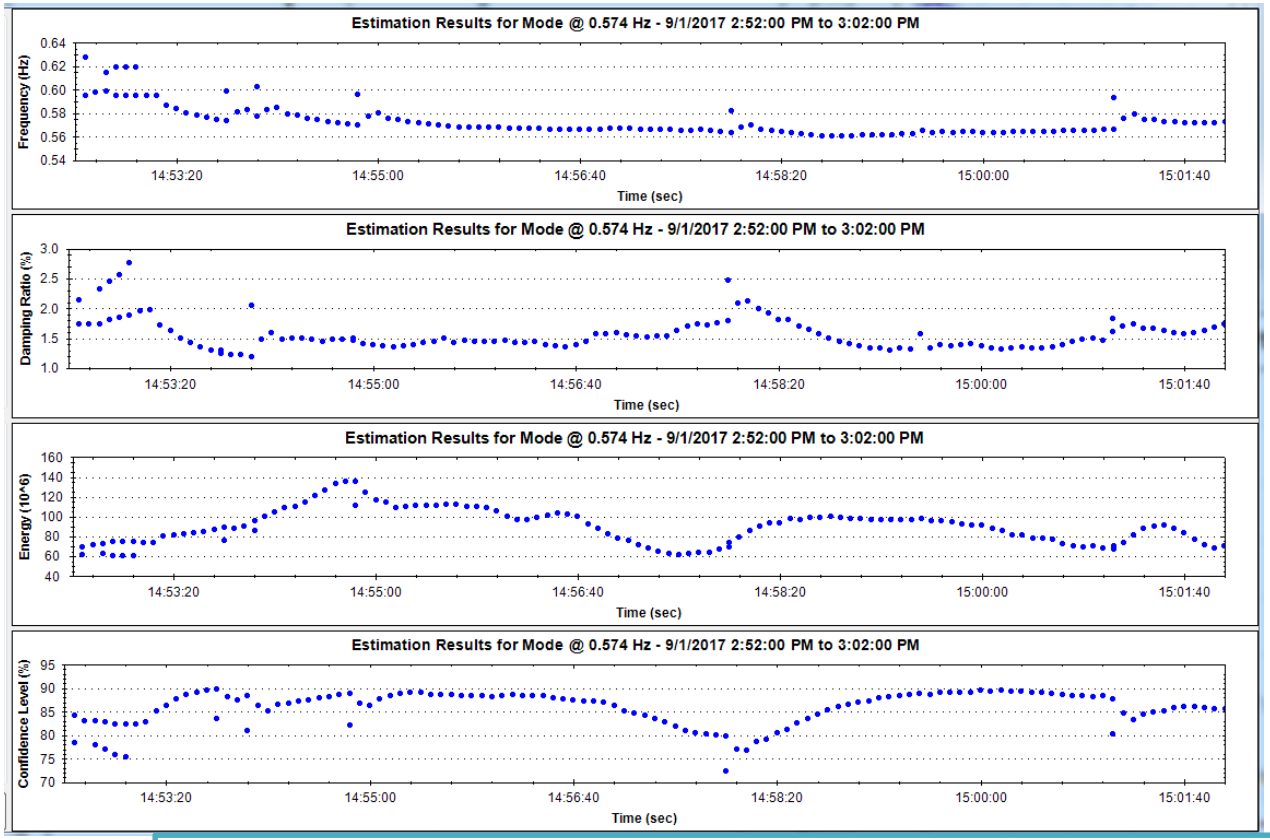
BC Mode Low Damping Case Study



Fast damping ratio reduce
Time: 14:39:01~14:49:04
Damping Ratio: 16:85% -> 8.8%

Low damping ratio valley
Time: 15:01:14~15:24:26
Damping ratio: [0.8%, 9.2%]

Modal Analysis by WSU Tools



Frequency: Continuous mode existence

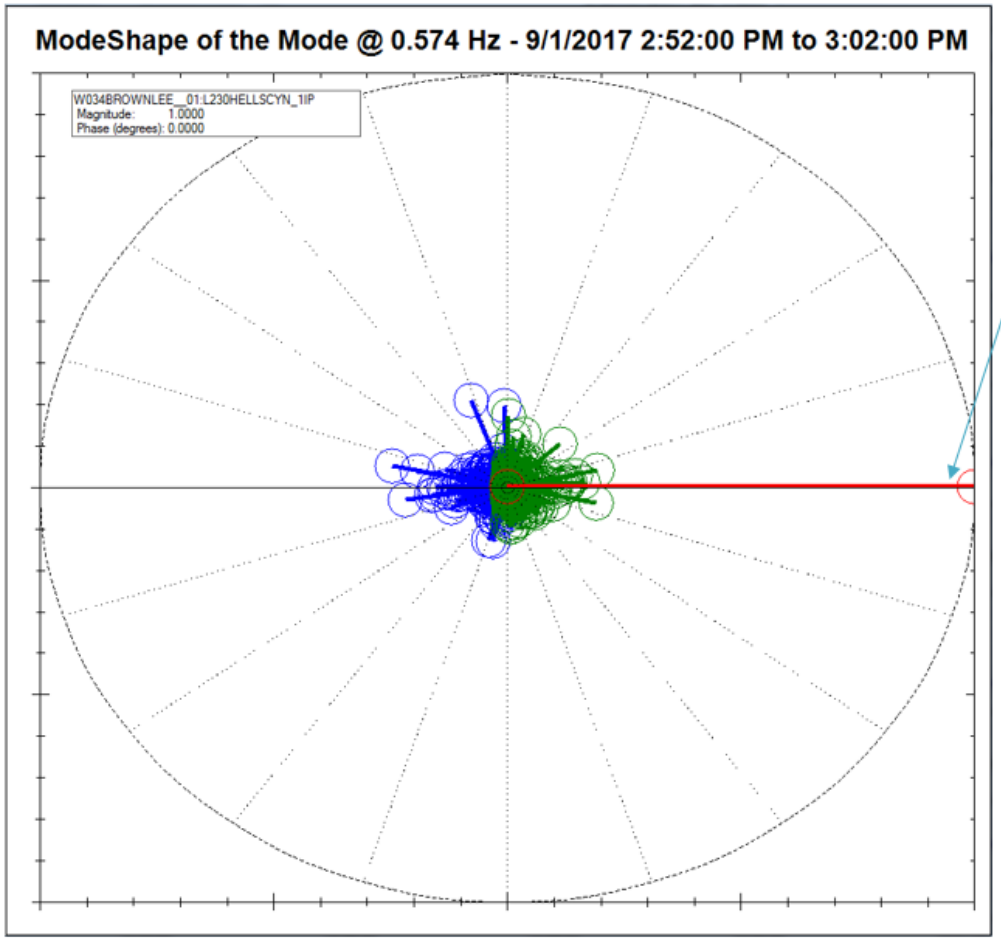
Damping ratio: Continuous low damping ratio

PSD energy: Continuous high PSD energy

Confidence level: Continuous high confidence level

The low damping oscillation mode continuously existed. According to the continuously high PSD energy and confidence level, it is believed there is a forced oscillation.

Mode Shapes



Typical mode shape

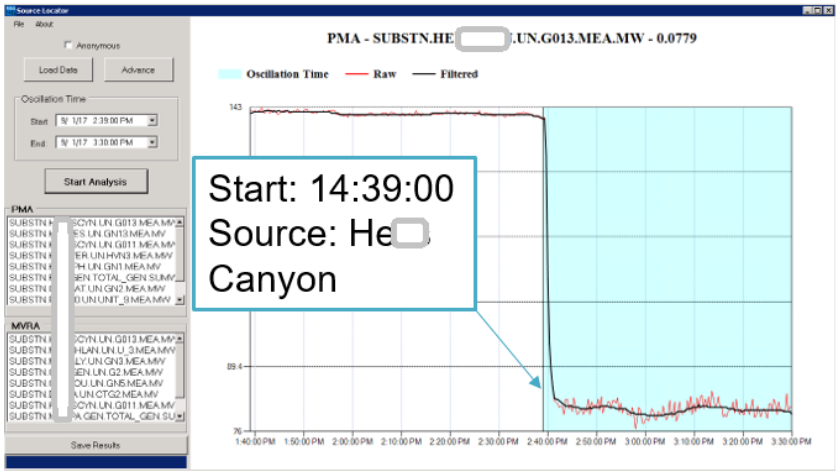
BRO CYN

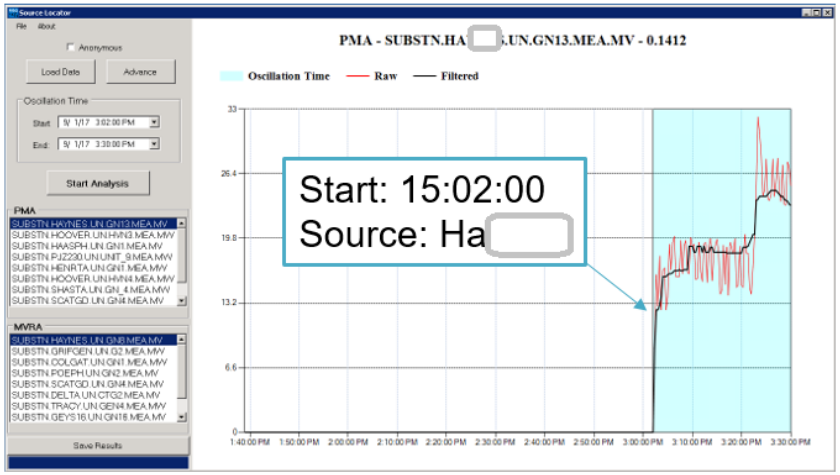
The top-first amplitude signal is significantly greater than others.

This signal is highly associated with the forced oscillation source.

FODSL Study Results

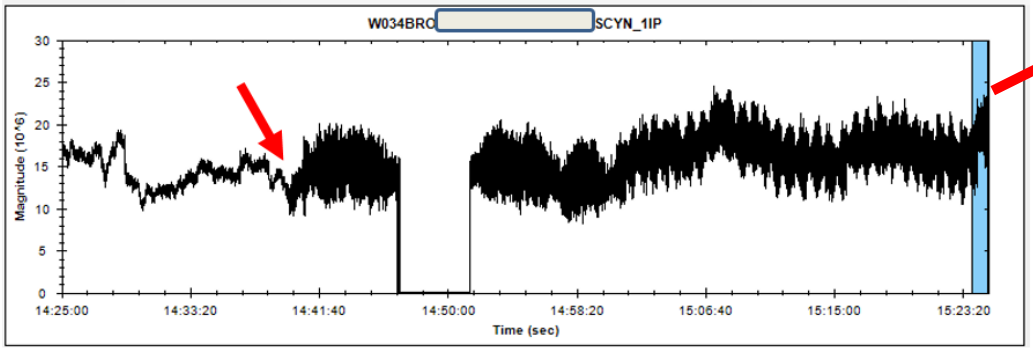
- FODSL localizes the source generators associated with a given forced oscillation.
- Data source: SCADA & PMU
- Two units are suspected for the source

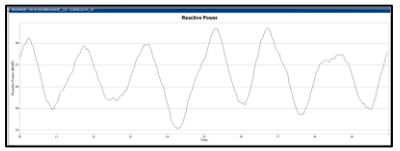




Mode Analysis on Individual PMU

- PMU signal on a 345kV line flow connecting one of suspected units confirms the oscillation

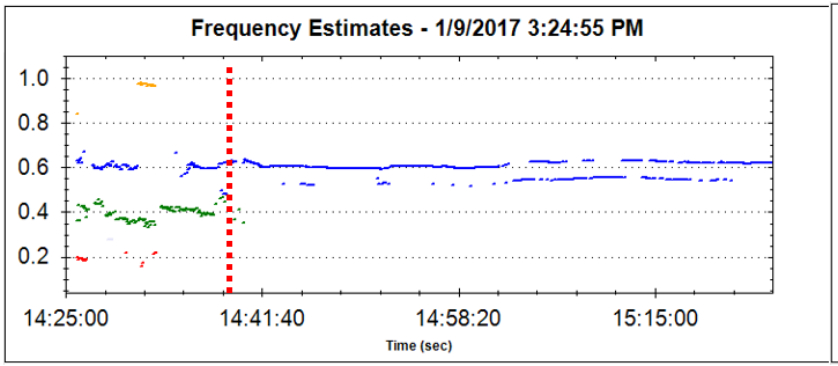


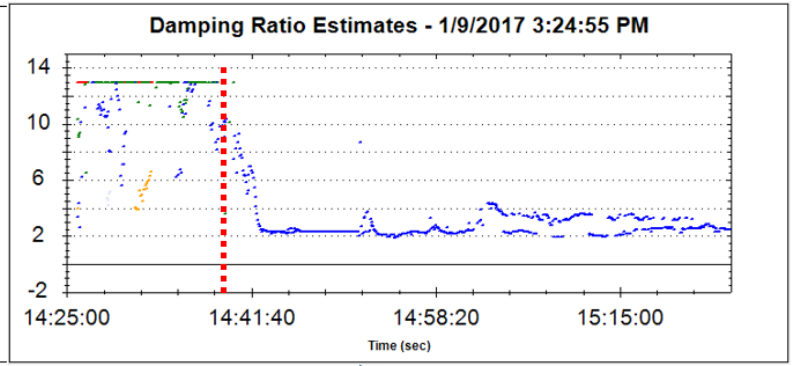


~0.6hz mode

PMU reactive power at BRO CYN

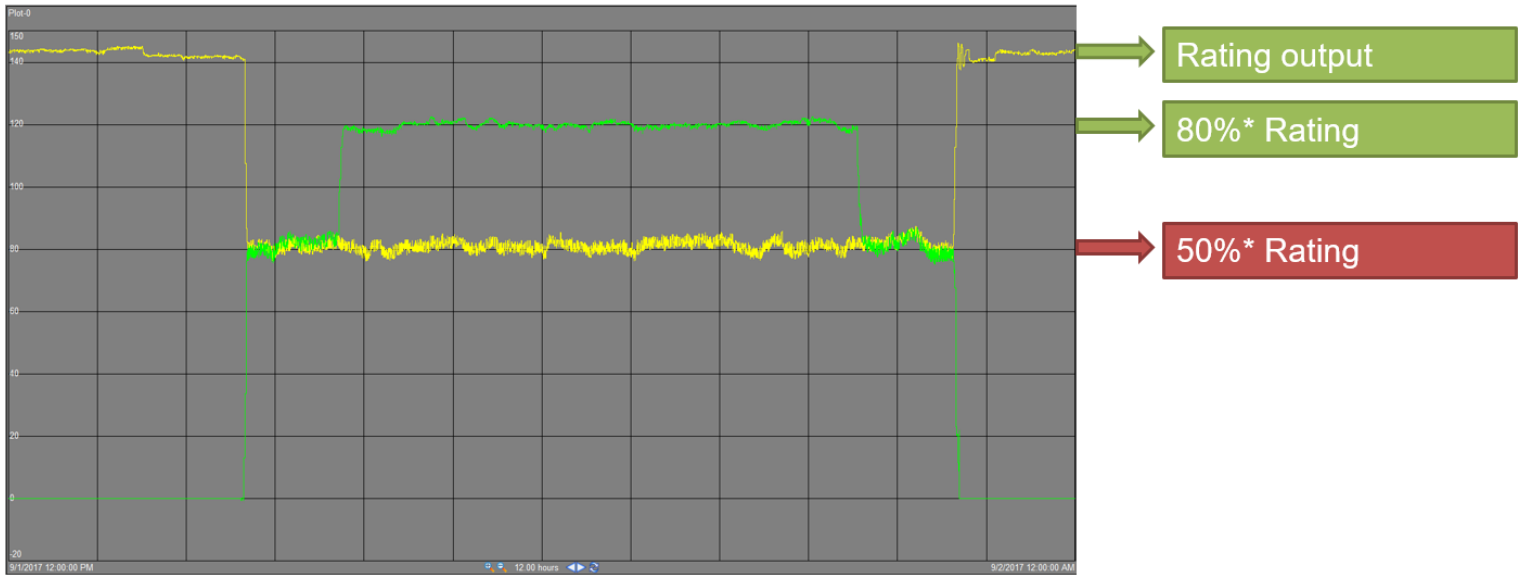
Low damping ratio





Verification by SCADA Data in PI

- The hydro units in Helxxx carried 50% Pmax load and was operated in “Rough Zone”, which resulted in this forced oscillation



Analyzing N-S Modes by Simulation

- Peak leverages online TSAT models, ePMU, SSAT and Oscillation analytical tools to
  - Perform correlation and sensitivity study on N-S modes e.g. critical contingencies, transfer levels, system conditions, and bus angle separation
  - Validate BPA's mitigation plans for NS modes
  - Build an offline study process to enable engineer validating mode meter results using SSAT and ePMU tools and developing training cases

2017 Summer Heavy Loading Case

- We simulated Sept 11 2017 peak hour case in TSAT under ambient situation plus a number of events leading the August 10, 1996 blackout
- SSAT study was performed against each event
- ePMU data stream was imported into WSU DMO tool to extract the modal characteristics
- TSAT simulation contains 30min data including
  - 10min ambient after the Chief Joe Brake insertion at t=0
  - Followed by 0min of events sequence (Event 1 to 9)
  - 10min ambient after COI transfer increase by 5% in 20s

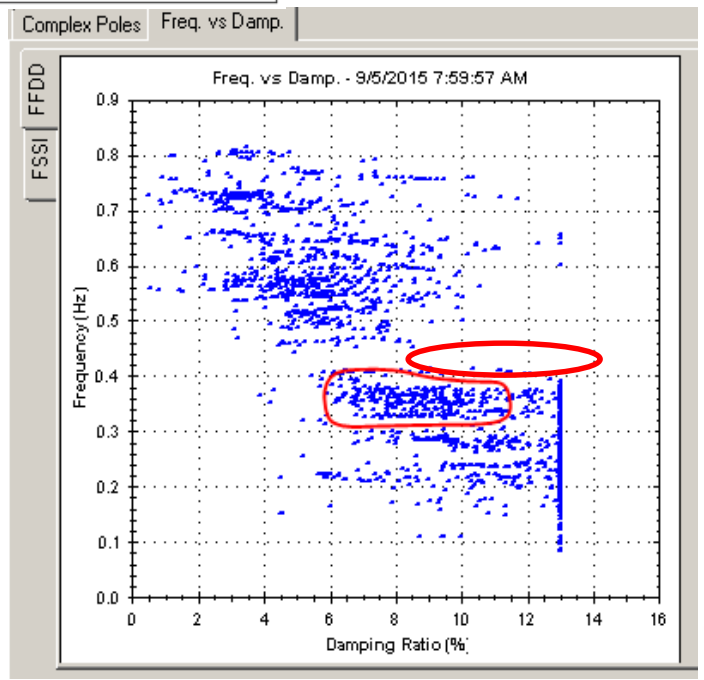
SSAT Study Results

NO	Event	SSAT Modal Analysis
	Base Case	15 Modes Are Available; 3 Modes Are Shown After Applying Filters N... | Real | Imaginary | Frequency(... | Damping(%) | Dominant State EW | -0.2664 | 2.3929 | 0.3808 | 11.06 | 70777 : COMA_24_GEN3 NSB | -0.2141 | 2.3885 | 0.3801 | 8.93 | 59908 : 29EDD3_13.8_G5 NSA | -0.1785 | 1.6447 | 0.2618 | 10.79 | 54342 : SUNDANCE_20_G04
1	500kV Big Eddy-OSTRNDER fault followed by line trip	15 Modes Are Available; 3 Modes Are Shown After Applying Filters N... | Real | Imaginary | Frequency(... | Damping(%) | Dominant State EW | -0.2677 | 2.3927 | 0.3808 | 11.12 | 70777 : COMA_24_GEN3 NSB | -0.2109 | 2.3893 | 0.3803 | 8.79 | 59908 : 29EDD3_13.8_G5 NSA | -0.1786 | 1.6456 | 0.2619 | 10.79 | 54342 : SUNDANCE_20_G04
2	500kV John Day-Marion fault followed by line trip	15 Modes Are Available; 3 Modes Are Shown After Applying Filters N... | Real | Imaginary | Frequency(... | Damping(%) | Dominant State EW | -0.2674 | 2.3923 | 0.3807 | 11.11 | 70777 : COMA_24_GEN3 NSB | -0.2112 | 2.3898 | 0.3803 | 8.80 | 59908 : 29EDD3_13.8_G5 NSA | -0.1789 | 1.6463 | 0.2620 | 10.80 | 54342 : SUNDANCE_20_G04
3	500kV Keeler-Alston fault followed by line trip	15 Modes Are Available; 3 Modes Are Shown After Applying Filters N... | Real | Imaginary | Frequency(... | Damping(%) | Dominant State EW | -0.2643 | 2.3898 | 0.3803 | 10.99 | 70777 : COMA_24_GEN3 NSB | -0.2106 | 2.3755 | 0.3781 | 8.83 | 59908 : 29EDD3_13.8_G5 NSA | -0.1736 | 1.6300 | 0.2594 | 10.59 | 54490 : GENESEE_21_G03
4	230kV Ross-Lexington fault followed by line trip:	15 Modes Are Available; 3 Modes Are Shown After Applying Filters N... | Real | Imaginary | Frequency(... | Damping(%) | Dominant State EW | -0.2643 | 2.3913 | 0.3806 | 10.99 | 70777 : COMA_24_GEN3 NSB | -0.2101 | 2.3742 | 0.3779 | 8.81 | 59908 : 29EDD3_13.8_G5 NSA | -0.1723 | 1.6279 | 0.2591 | 10.52 | 54490 : GENESEE_21_G03
5	McNarry trip all units: For SSAT studies, we increase the generation of John_Day, Grand_Coulee, Chief_Joe manually	15 Modes Are Available; 2 Modes Are Shown After Applying Filters N... | Real | Imaginary | Frequency(... | Damping(%) | Dominant State EW | -0.2609 | 2.3900 | 0.3804 | 10.85 | 70777 : COMA_24_GEN3 NSA | -0.1670 | 1.6220 | 0.2581 | 10.24 | 54490 : GENESEE_21_G03
6	500kV Buckley-Grizzly line trip	15 Modes Are Available; 2 Modes Are Shown After Applying Filters N... | Real | Imaginary | Frequency(... | Damping(%) | Dominant State EW | -0.2590 | 2.3906 | 0.3805 | 10.77 | 70777 : COMA_24_GEN3 NSA | -0.1651 | 1.6069 | 0.2557 | 10.22 | 54490 : GENESEE_21_G03
7	500kV Malin-Round Maountain #2 line trip	15 Modes Are Available; 2 Modes Are Shown After Applying Filters N... | Real | Imaginary | Frequency(... | Damping(%) | Dominant State EW | -0.2532 | 2.3910 | 0.3805 | 10.53 | 70777 : COMA_24_GEN3 NSA | -0.1626 | 1.5889 | 0.2529 | 10.18 | 54490 : GENESEE_21_G03

SSAT vs DMO

8	500kV John Day-Grizzly #1 line trip	15 Modes Are Available; 3 Modes Are Shown After Applying Filters N... Real Imaginary Frequency(... Damping(%) Dominant State EW -0.2569 2.3906 0.3805 10.68 70777 : COMA_24_GEN3 NSB -0.2110 2.3131 0.3681 9.08 59908 : 29EDD3_13.8_G5 NSA -0.1540 1.5418 0.2454 9.94 54490 : GENESEE_21_G03
9	500kV Malin-Round Maountain #1 line trip	213 Modes Are Available; 2 Modes Are Shown After Applying Filters N... Real Imaginary Frequency(... Damping(%) Dominant State EW -0.2491 2.3655 0.3765 10.47 70777 : COMA_24_GEN3 NSB -0.2145 2.1669 0.3449 9.85 59908 : 29EDD3_13.8_G5
10	500kV John Day-Grizzly #2 line trip	Powerflow Diverges

- The SSAT results table shows the effect of tripping lines on the damping of Modes A, B, and East-West



Analysis of Simulation Results

- Both SSAT and DMO estimate N-S Modes damping mostly between 8-10% on the case
- System events e.g. the line and unit tripping does not necessarily lowers modes damping
- Damping decreases with transfer increase e.g. Increase the loads in SCE and PGAE areas by 5% and the generation in AESO and BC Hydro on a 2017 highest peak load case, the damping of Mode A decreases from 12. 5% to 4.5%.

No.	Real	Imaginary	Frequency(...	Damping(%)	Dominant State
E-W	-0.2073	2.4801	0.3947	8.33	70777 : COMA_24_GEN3
NSB	-0.0820	2.3644	0.3763	3.46	70777 : COMA_24_GEN3
NSA	-0.0759	1.6719	0.2661	4.53	54490 : GENESEE_21_G03

Conclusion

- Peak uses both MAS/Mode Meter and WSU's RT-FODSL tools to monitor system oscillations
  - Many oscillation events were detected/analyzed in collaboration with entities over the last years
  - Set initial alarms for N-S Modes for validation and create weekly oscillation report for routine review
  - Work with WSU to improve its oscillation software
  - Generate ePMU data from online TSAT tool for N-S Modes analysis using SSAT and DMO tools

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