Pacific Northwest NATIONAL LABORATORY

Automated Creation of Varying Penetrations of GFM IBRs for Western Interconnection Wide-area Oscillation Study

2023 May WECC MVS Meeting @Vancouver, BC

***PNNL*:** Xiaoyuan Fan, Wei Du, Quan Nguyen, Marcelo Elizondo, Shaobu Wang, Jim Follum, Slaven Kincic, Henry Huang, Yousu Chen, Shuchismita Biswas, Xue Lyu, Kaustav Chatterjee, Sameer Nekkalapu, Hisham Mahmood

Binghamton University: Prof. Ning Zhou

Montana Tech. University: Prof. Dan Trudnowski

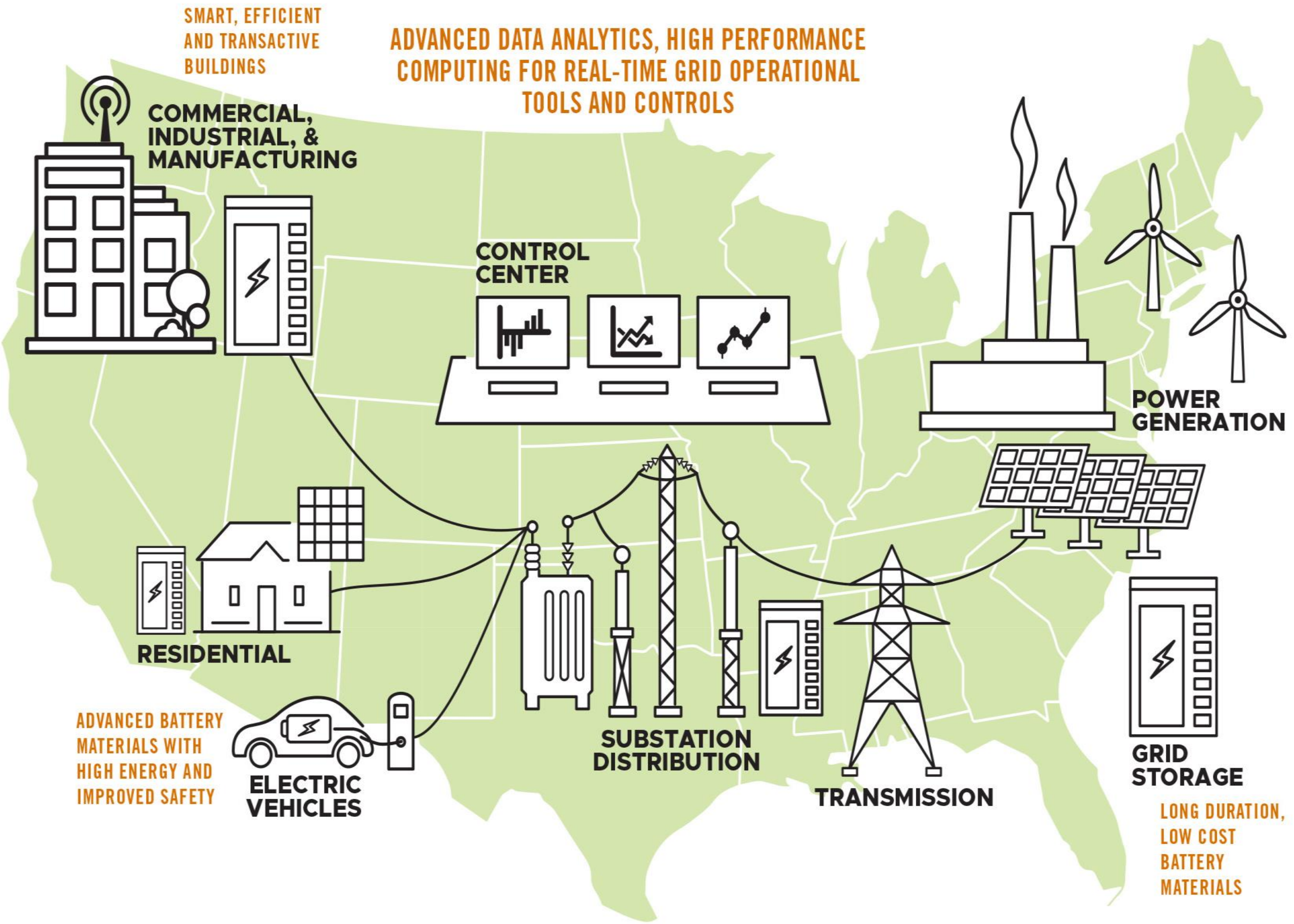
Technical Advisors: Bahram Barazesh

U.S. DEPARTMENT OF ENERGY BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

PNNL-SA-185348, unlimited distribution.

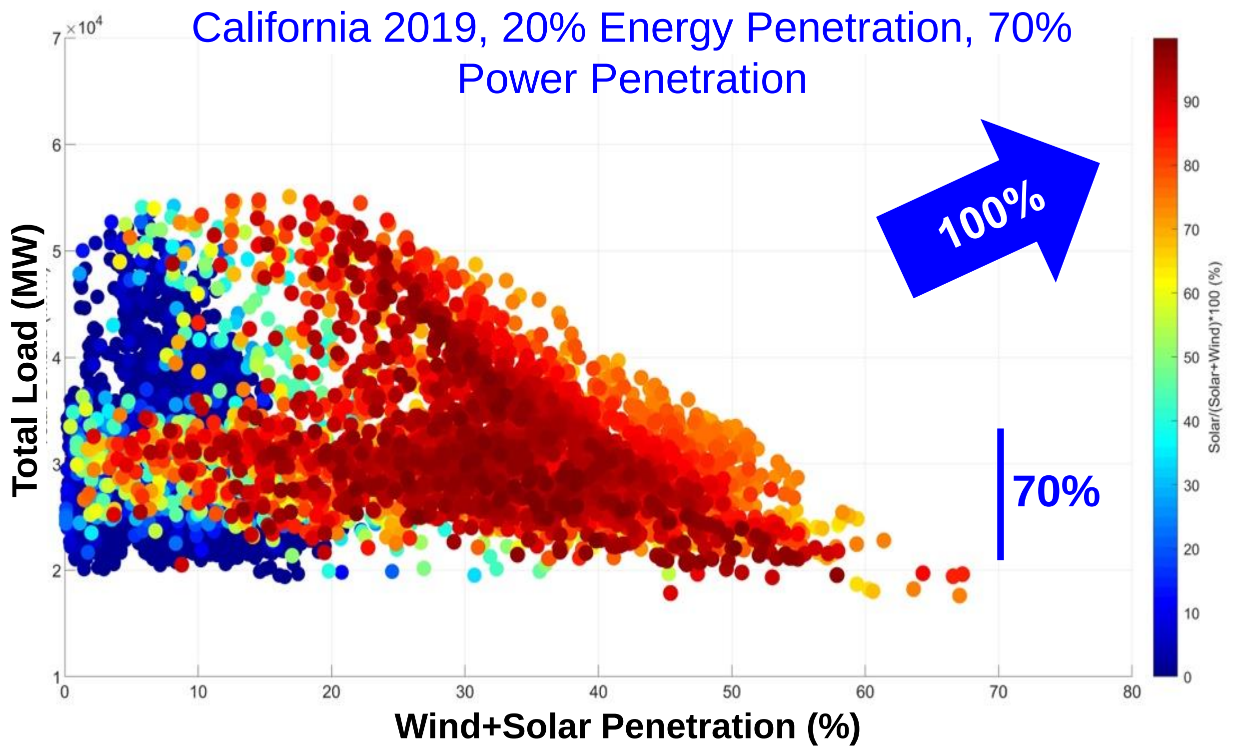
VISION: Support 100% Energy Decarbonization through Grid Control and Energy Storage



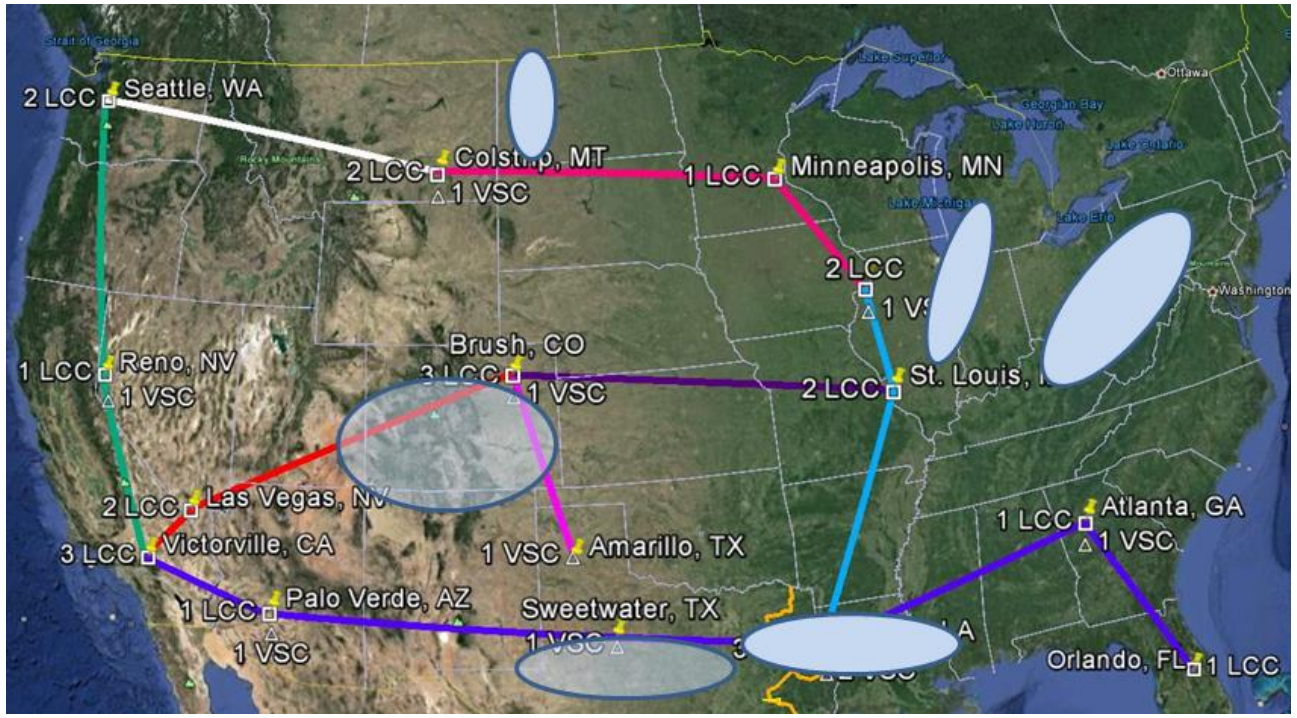
Pacific Northwest
NATIONAL LABORATORY

Energy Transformation Vision:
100% decarbonization & new grid infrastructure

- The Biden administration adopted ambitious decarbonization plans, 100% clean electricity by 2035 and net-zero emissions across the economy by 2050
- Require dramatic amounts of additional utility-scale and distributed zero-carbon generation to decarbonize the power system
- In addition, a well-designed new transmission infrastructure “Macrogrid” is needed to ensure transferring large amounts of clean energy from where it is produced to where it is needed



Data source: US EIA Hourly Data 2020



Data source: Dale Osborn "The Macrogrid", T&D world,2018 https://www.tdworld.com/digital-innovations/hvdc/article/20971033/the-macrogrid-part-ii

Pacific Northwest NATIONAL LABORATORY

Wide-Area Oscillation Assessment and Trending Analysis considering High-penetration of IBRs & DERs

- **Period:** August 2022 to May 2025, now at 10th month (10/34)
- Extend our existing developed methodologies to further investigate and improve our fundamental understanding of what are the new oscillation trends and what new oscillation modes will appear with respect to:
  - emerging advanced grid-forming IBR control strategies and DER impacts
  - potential new “Macrogrid” transmission infrastructure
- Develop additional advanced control strategies to stabilize the wide-area oscillation modes under high penetration of IBRs to achieve 100% decarbonization
  - additional PSS-like advanced control strategies for the IBRs to damp the wide-area oscillation
  - novel strategies to dispatch generation mix (conventional and renewable generators) in the “Macrogrid” infrastructure to damp the wide-area oscillation

DOE OE AGM funded Research (FY22~FY25) Oscillation trending for 100% decarbonization: Grid Evolution, IBRs Integration, and Macro-grid

Task 1: Analyze emerging new IBR control technologies

- Grid-forming control and impact on real systems
- Impact of distributed energy resource on real systems
- Impact of hybrid energy systems on real networks

Task 2: Analyze potential new electric infrastructures

- Realistic/planned locations of the additional renewables
- Dramatically changed operation condition and power flow
- HVDC Control strategies

Assess

Assess

- What is the new oscillation trend?
- What new oscillation modes will appear?

Improve

Improve

Task 3: Develop novel additional feed-back control method to damp the oscillation

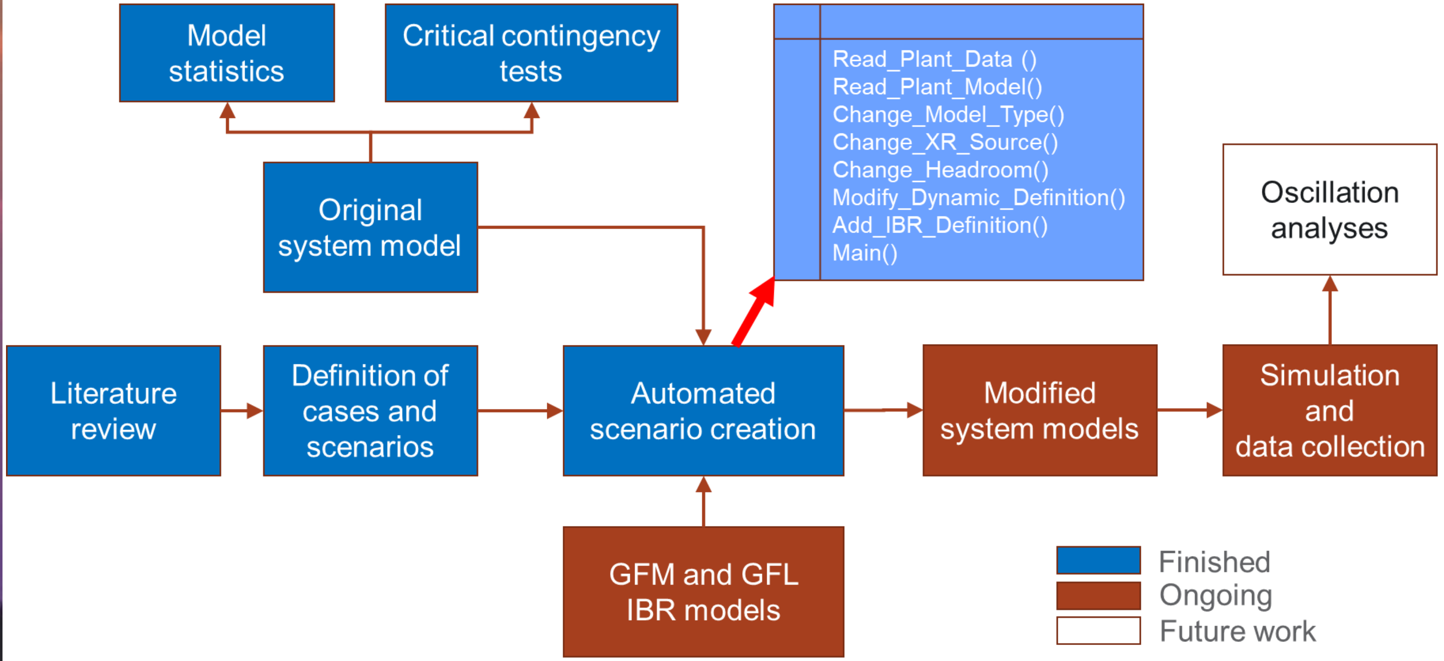
- PSS-like damping control for Grid-following
- PSS-like damping control for Grid-forming

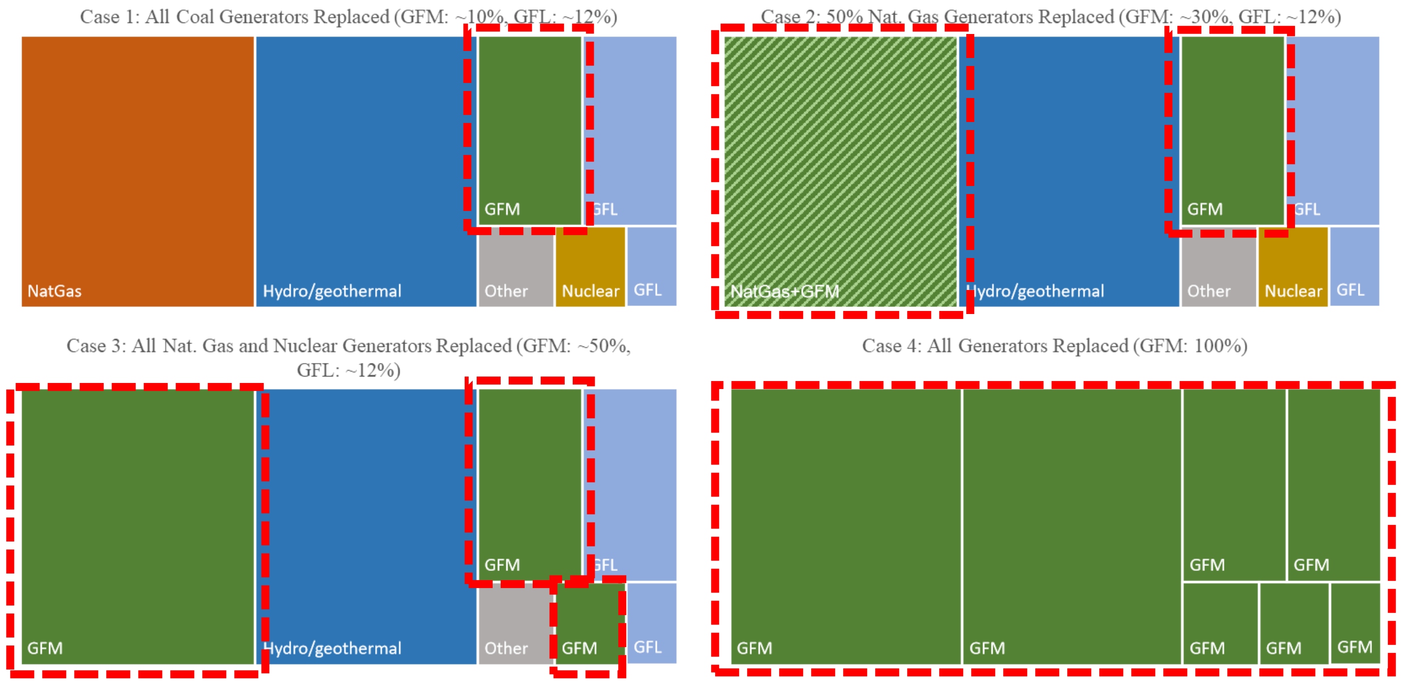
Task 4: Develop novel operational strategies for dispatching generation mix optimally

- Analytic-based method
- Data-based method

Task 1 Deliverables and Results: Oscillation cases with high penetration IBRs

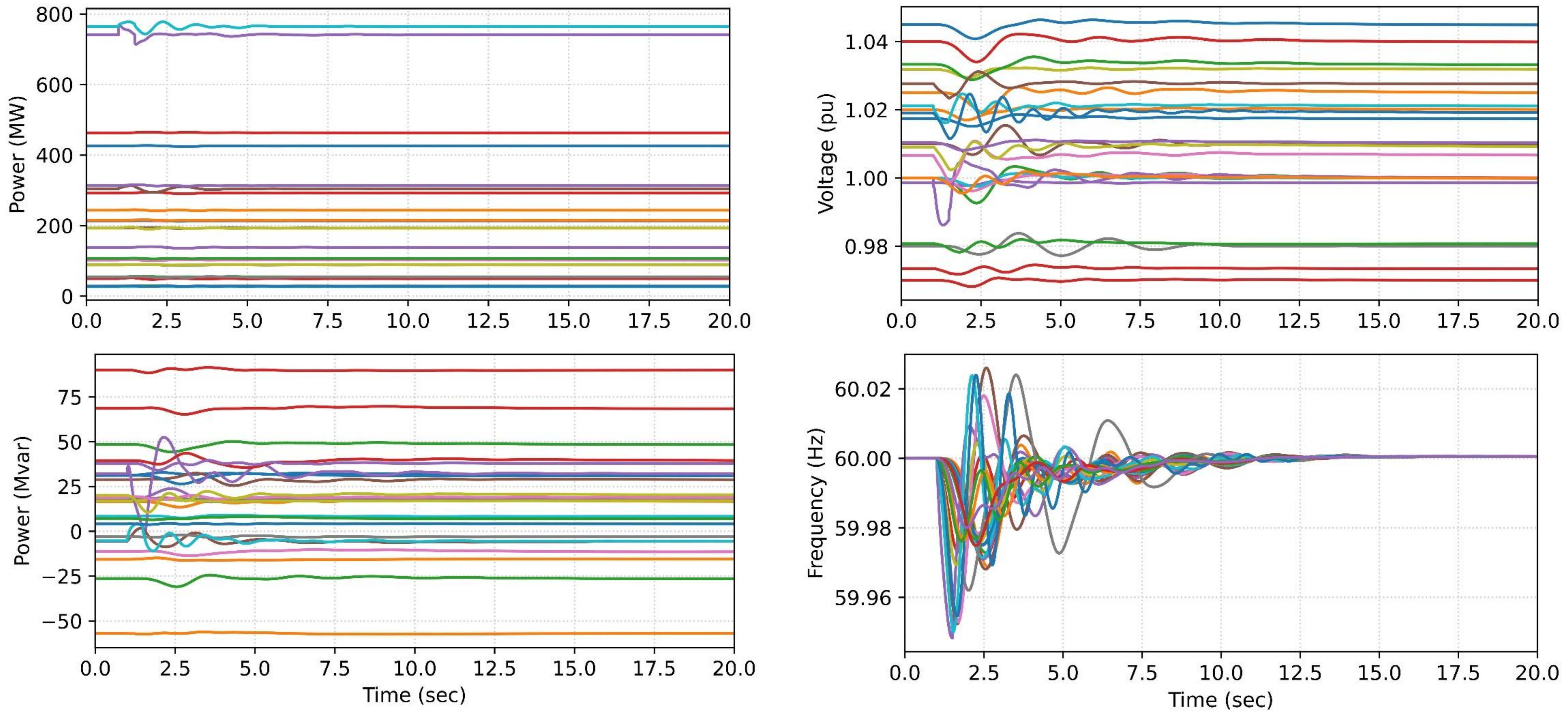
- Project Task 1 completed the first batch of WECC model with high penetration of grid-forming Inverter Based Resources (GFM IBRs), we automated the case generation process, and 4 cases (20%, 40%, 60%, and 100% GFM IBR) of and hosted an internal review session for this deliverable
- Project Task 1 performed literature review on oscillation evaluation with both EMT and phasor-domain methods considering IBRs, and completed a two-page white paper summarizing the major findings
- Project Task 1 continued the coordination of DER modelling with another ongoing AGM project, and explored composite load model representation for PSSE for DER representations





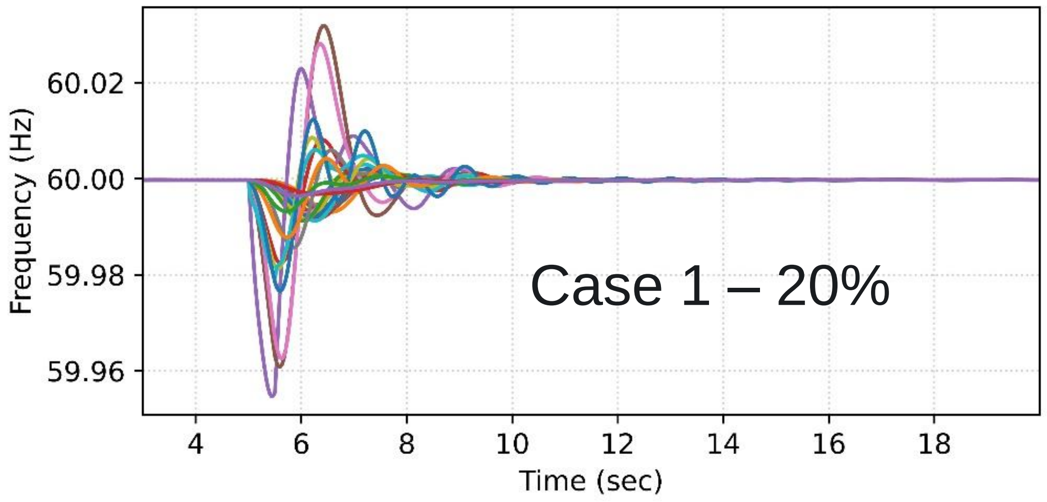
Task 1 Original WECC 2030 Case (basecase)
Contingency 1 – Chief Joseph Brake Insertion

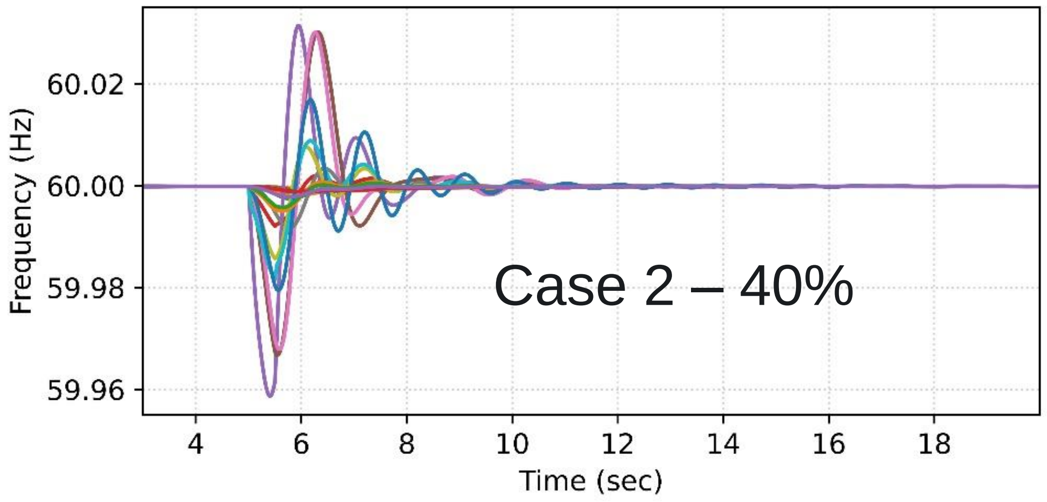
- Turn ON and then OFF the load component at Chief Joseph Brake Site
  - Widely adopted and used in Western Interconnection (WI) oscillation study

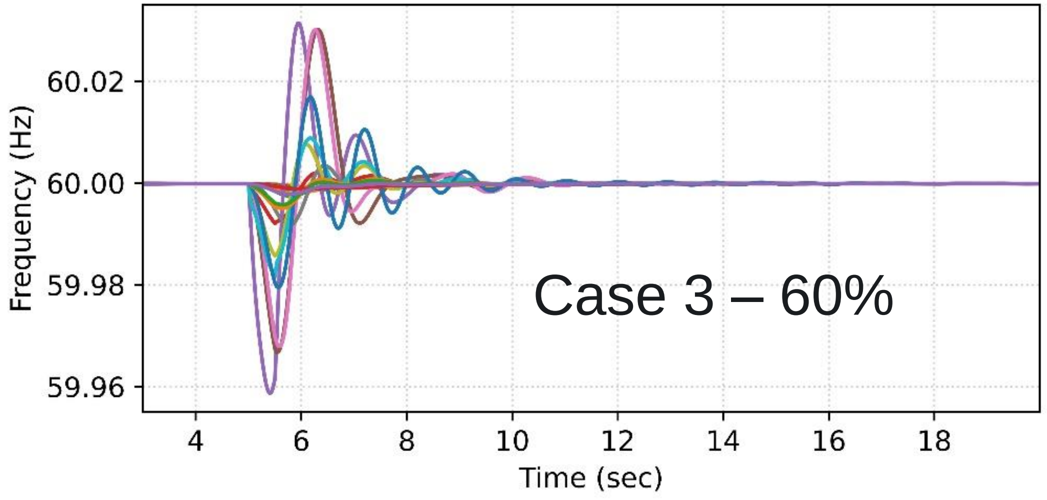


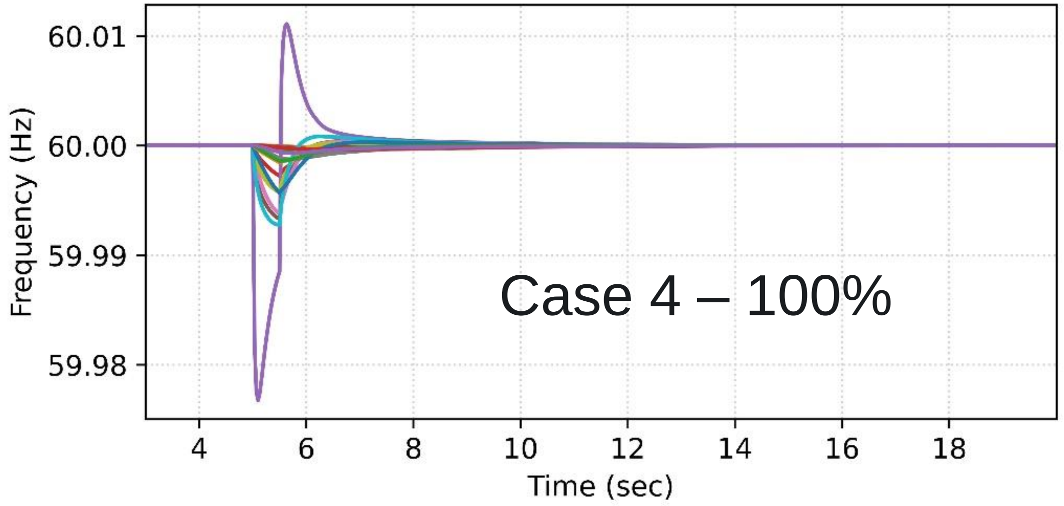
Task 1 GFM High-Penetration Simulation Results
Contingency 1 – Chief Joseph Brake Insertion

- **Contingency 1**









Inter-area modes in the Western Interconnection: Brief Overview

Mode	Frequency (Hz)	Shape	
North-South A	0.2-0.3	Alberta vs. system	
North-South B	0.35-0.45	Alberta vs (BC+Northern US) vs Southern US	Lightly damped, most widespread
British Columbia A	0.5-0.72	BC vs Northern US vs Southern US	
British Columbia B	0.6-0.72	Western edge vs system vs eastern edge	
Montana	0.7-0.9	Montana vs system	Driven mainly by the Colstrip power plant
East-West A	0.35-0.45	(Colorado+Eastern Wyoming) vs system	

Modes of Inter-Area Power Oscillations in the Western Interconnection, Western Interconnection Modes Review Group, 2021 https://www.wecc.org/Reliability/Modes%20of%20Inter-Area%20Power%20Oscillations%20in%20the%20WI.pdf

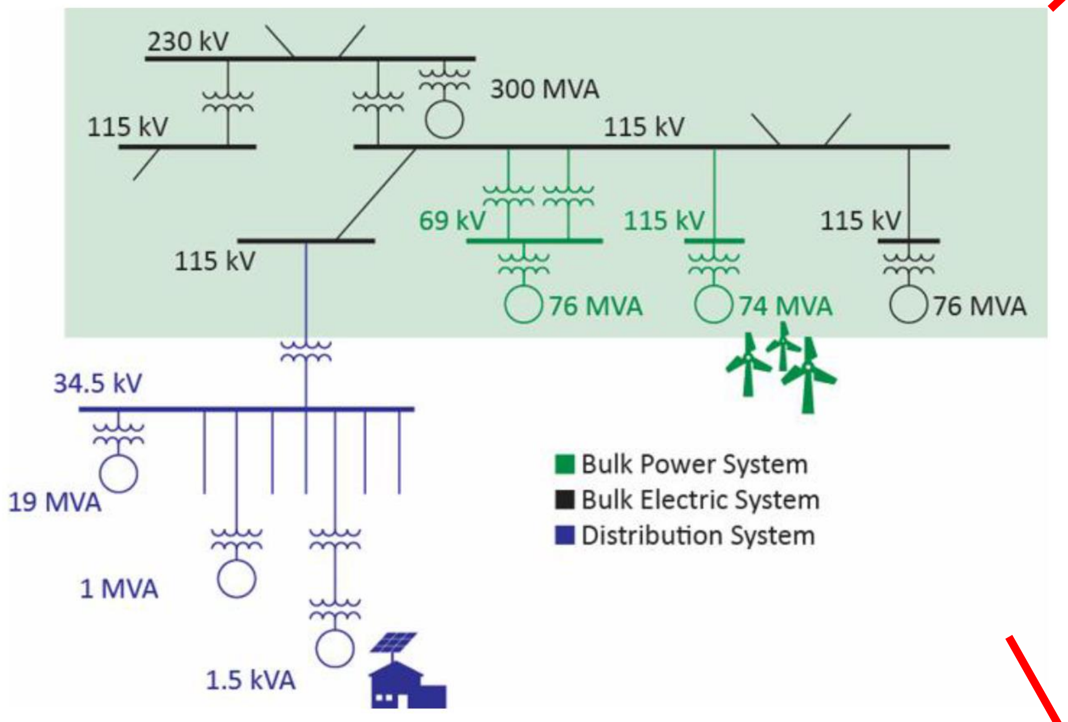
Task 1 Deliverables and Results:
WI *North-South modes* in Oscillation Evaluation for High-RE cases

- Mode estimates obtained (frequency, damping ratio):

Base case	**20% GFM penetration**	**40% GFM penetration**	**60% GFM penetration**
(0.27 Hz, 17%)	(0.74 Hz, 23%)	(0.78 Hz, 21%)	(0.78 Hz, 23%)
(0.38 Hz, 14%)	(0.53 Hz, 24%)	(0.52 Hz, 20%)	(0.51 Hz, 19%)
(0.62 Hz, 17%)			
(0.85 Hz, 18%)			

- This behavior is expected, because large synchronous generators in the planning model have been replaced by GFM inverters.

Task 1 Deliverables and Results:
NERC *Distributed Energy Resource Strategy*



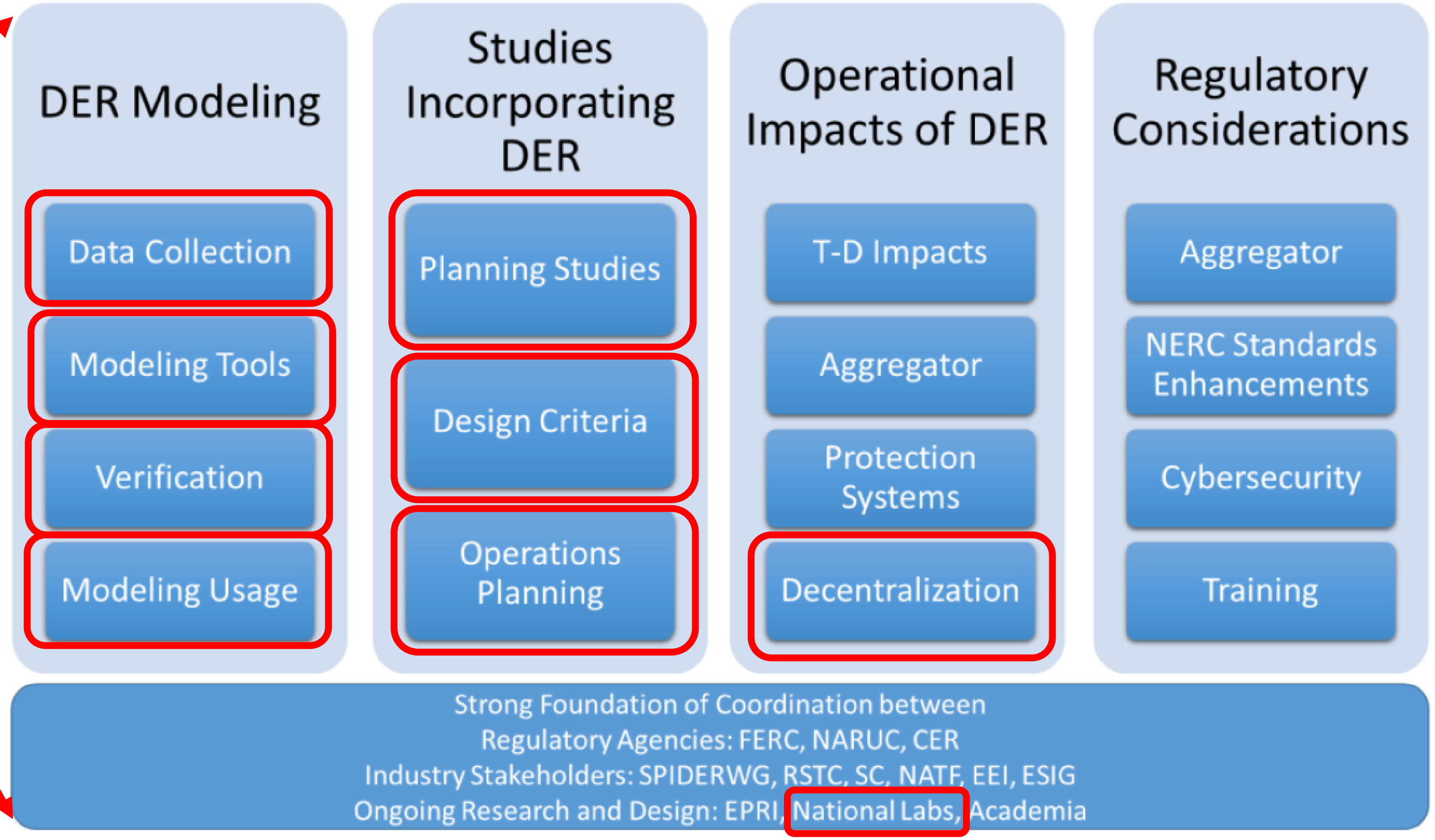


Figure 4: NERC DER Risk Mitigation Strategy

[*] The NERC document is available online: https://www.nerc.com/comm/RSTC/Documents/NERC_DER%20Strategy_2022.pdf

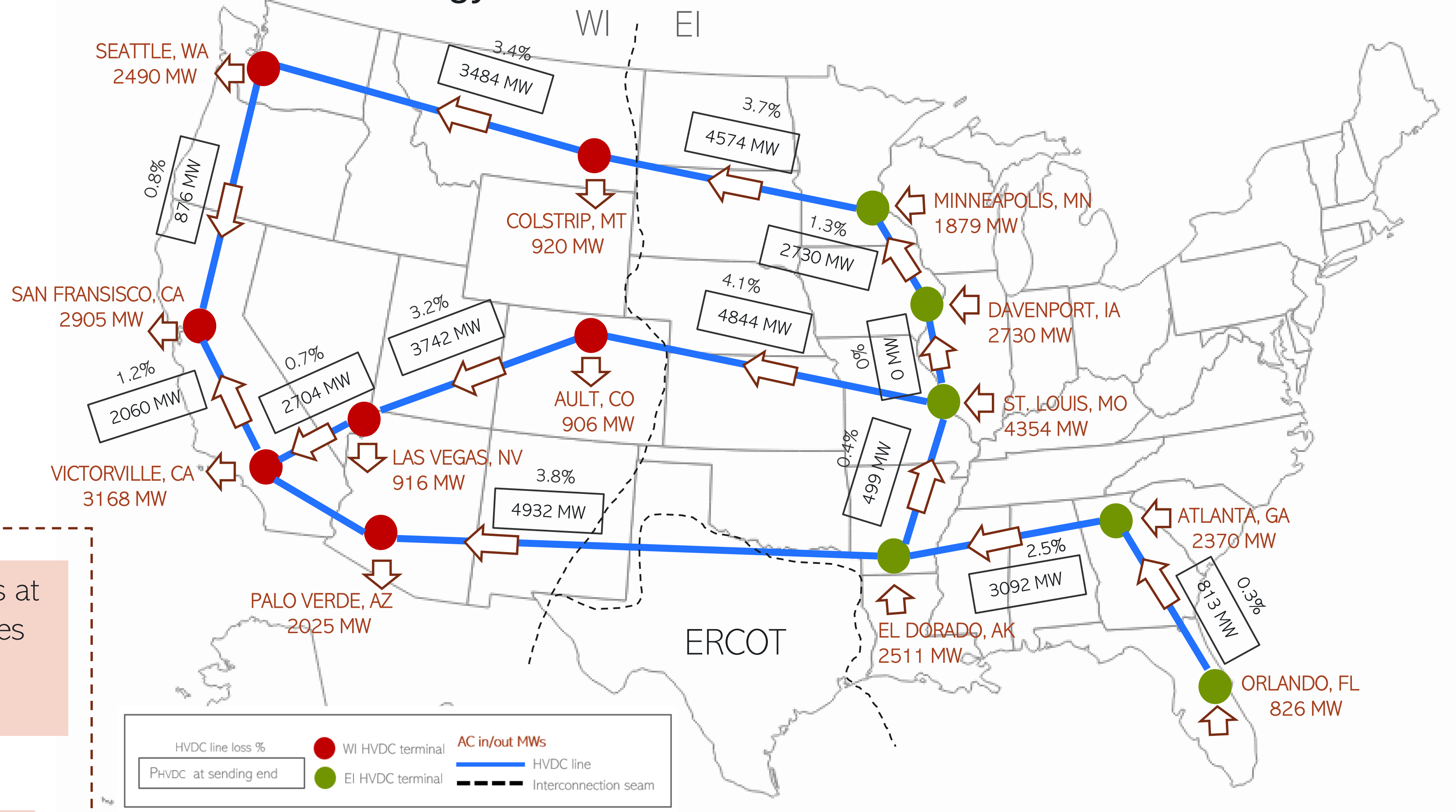
Task 2 Deliverables and Results:
MTDC Macrogrid Combining EI and WECC Systems

- WECC system [*] modified to reflect high renewable penetration scenario – 60% of synchronous generation capacity replaced with grid forming inverter-interfaced renewable energy

- Implemented in PSS/E in two phases:

  (1) Full-model of 60% GFM-interfaced WECC with three lumped generators (MN, MO, and AR) representing EI

  (2) Further extension to full-model of EI



Steps involved in the model preparation

Preparing the base case WECC model with 60% GFM ✓

for (1) → Model DC injections at respective AC nodes with fictitious generators → Adequately scale loads in respective/ neighboring areas ✓

for (2) → Combining the models in PSS/E with uniform bus numbers, solvers, and obtain converged power flow ✓

Base case EI model → for (2)

→ Solve for AC power flow Obtain convergence ✓ → Write user-defined dynamic models for VSC-HVDC/MTDC ✓ → Solve for AC-DC power flow Obtain convergence (in-progress) → Perform dynamic simulations & Check performance (in-progress)

✓ completed ✓ in-progress

[*] M. A. Elizondo et al., "HVDC macrogrid modeling for power-flow and transient stability studies in north american continental-level interconnections," in CSEE Journal of Power and Energy Systems, vol. 3, no. 4, pp. 390-398, Dec. 2017, doi: 10.17775/CSEEJPES.2017.00420.

Project Industry Advisory Board

- Six participating IAB members
  - Emanuel E. Bernabeu (PJM)
  - John Paul Skeath (NERC)
  - Yunzhi Cheng (ERCOT)
  - Song Wang (PGE)
  - Urmila Agrawal (CAISO)
  - Asher Steed (BC Hydro)
- (Done) First meeting on 9/30, 2022
- (Done) 2nd meeting on Jan. 30, 2023
- (Next) 3rd meeting in May/June, 2023
- Annual review meeting (to be scheduled)

PNNL Team and University Collaborators


Xiaoyuan Fan, PI


Henry Huang, manager


Yousu Chen, manager


Ning Zhou,
Binghamton U.


Dan Trudnowski,
Montana Tech.


Wei Du,
Task 1 Lead


Marcelo Elizondo,
Task 2 Lead


Shaobu Wang,
Task 3 Lead


Jim Follum,
Task 4 Lead


Slaven Kincic,
project advisor


Quan Nguyen


Shuchismita Biswas


Xue Lyu


Kaustav Chatterjee


Sameer Nekkalapu


Hisham Mahmood

DOE OE AGM funded Research (FY22~FY25) Oscillation trending for 100% decarbonization: Grid Evolution, IBRs Integration, and Macro-grid

Task 1: Analyze emerging new IBR control technologies

- Grid-forming control and impact on real systems
- Impact of distributed energy resource on real systems
- Impact of hybrid energy systems on real networks

Task 2: Analyze potential new electric infrastructures

- Realistic/planned locations of the additional renewables
- Dramatically changed operation condition and power flow
- HVDC Control strategies

Assess

Assess

- What is the new oscillation trend?
- What new oscillation modes will appear?

Improve

Improve

Task 3: Develop novel additional feed-back control method to damp the oscillation

- PSS-like damping control for Grid-following
- PSS-like damping control for Grid-forming

Task 4: Develop novel operational strategies for dispatching generation mix optimally

- Analytic-based method
- Data-based method

Pacific Northwest
NATIONAL LABORATORY

Acknowledgement:

Department of Energy

Office of Electricity

Advanced Grid Modeling (AGM) Program

Thank you

Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by **Battelle** *Since 1965*

Xiaoyuan Fan, PhD
Senior Engineer & Team Leader,
Power Electronics

DISTRIBUTED SYSTEMS

Phone: (509) 371-7650
xiaoyuan.fan@pnnl.gov

902 BATTELLE BLVD

Richland, WA 99354
www.pnnl.gov