<Public>

Integrated Modeling of Renewable, Storage, MTDC for Wide-area Oscillation Assessment and Trending Analysis

2024 May WECC Modeling and Validation Subcommittee Meeting

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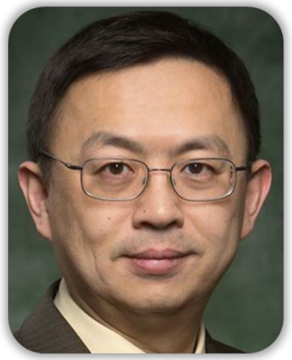
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DOE OE AGM funded Research (FY22~FY25) Oscillation trending for 100% decarbonization: Grid Evolution, IBRs Integration, and Macro-grid

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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

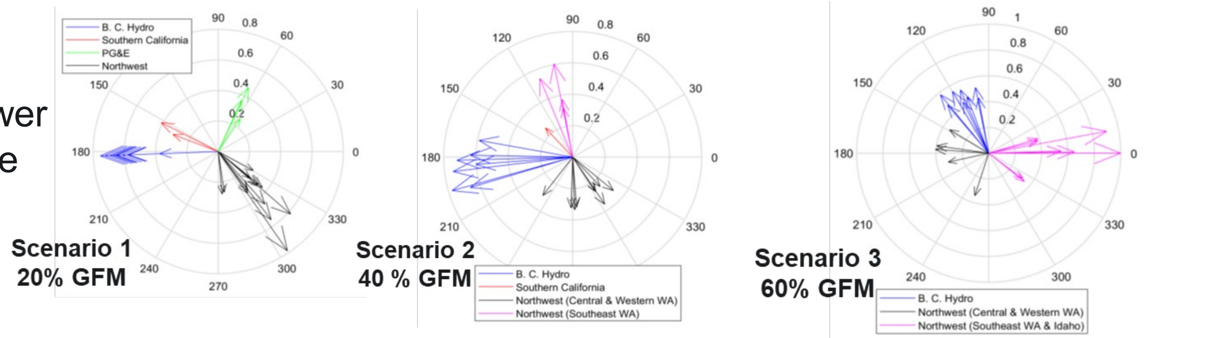
Task 4: Develop novel operational strategies for dispatching generation mix optimally

- Analytic-based method
- Data-based method

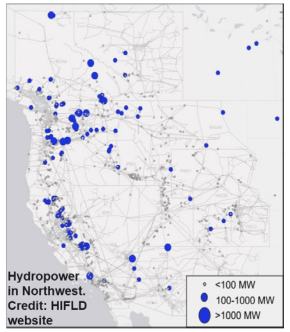
Completed In-progress Next-year-task

FY23 Achievement Summary & Highlights

Task 1 Preliminary observation for grid integration of IBRs (REGFM_A1): Hydropower generation in Northwest may drive the emergence of new mode (0.72 Hz) with limited geographical spread, potentially well-damped.



Base case (0.27 Hz, 17%) (0.38 Hz, 14%) (0.62 Hz, 17%) (0.85 Hz, 18%) → 20% GFM penetration (All coal replaced) (0.69 Hz, 15.4%) → 40% GFM penetration (50% natural gas replaced) (0.71 Hz, 14%) → 60% GFM penetration (All natural gas + nuclear replaced) (0.72 Hz, 14.5%)



Task 1: Analyze emerging new IBR control technologies
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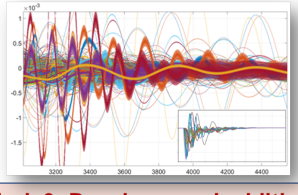
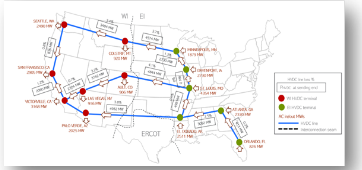


Assess → Assess

- 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
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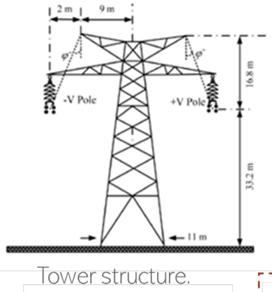
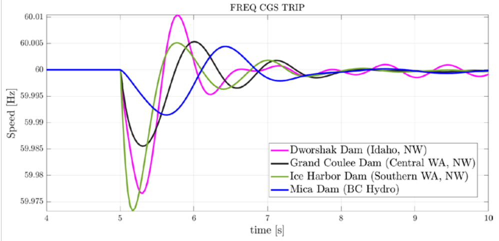
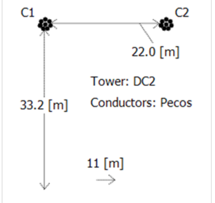
- PSS-like damping control for Grid-forming

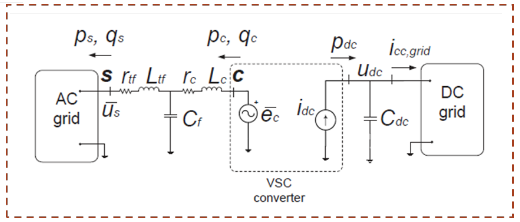
Task 4: Develop novel operational strategies for dispatching generation mix optimally
- Analytic-based method
- Data-based method

Task 2 Preliminary observation for Macrogrid (HVDC & 60% GFM IBRs): New generation pattern in WI with seven new HVDC injections, same/similar mode observed at 0.72 Hz but with mode shape differences. We have ongoing evaluation and testing for HVDC-based supplementary damping controller.









Task 3 Preliminary observation for damping control design: Small test system and preliminary controller design/testing showed that the location and participation of individual inverter (i.e., #2) matter, in the scenario of damping control design of multiple-inverter, multiple-synchronous machine network.

IBR Control	Freq (Hz)	DR (%)	IBR Control	Freq (Hz)	DR (%)	IBR Control	Freq (Hz)	DR (%)
1234	0.626	13.1%	12	0.620	12.8%	34	0.627	5.7%
123	0.616	12.4%	13	0.645	4.6%	1	0.644	4.6%
124	0.634	14.2%	14	0.613	6.0%	2	0.621	11.9%
134	0.610	6.0%	23	0.617	11.6%	3	0.643	4.2%
234	0.621	14.8%	24	0.620	14.6%	4	0.623	5.6%

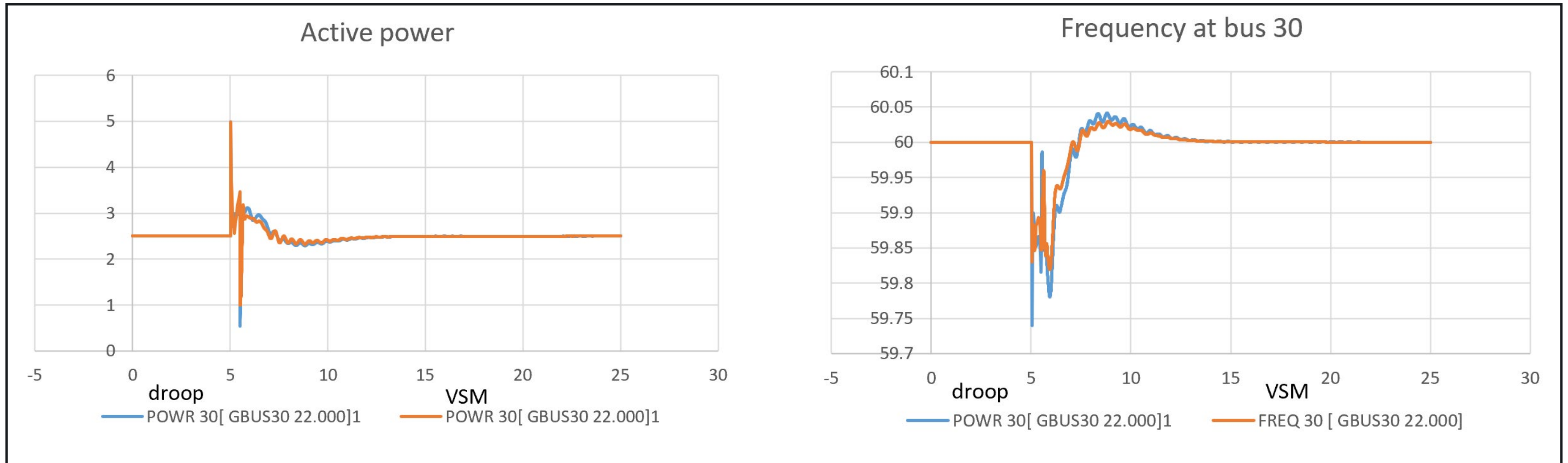
Task 4 Industry engagement & operational strategy: Closely work with the project technical advisors and industry advisors (PJM/NERC/PGE/BC Hydro/ERCOT), outreach to WECC and many members for data sharing and operational strategy development.

Project Industry Advisory Board

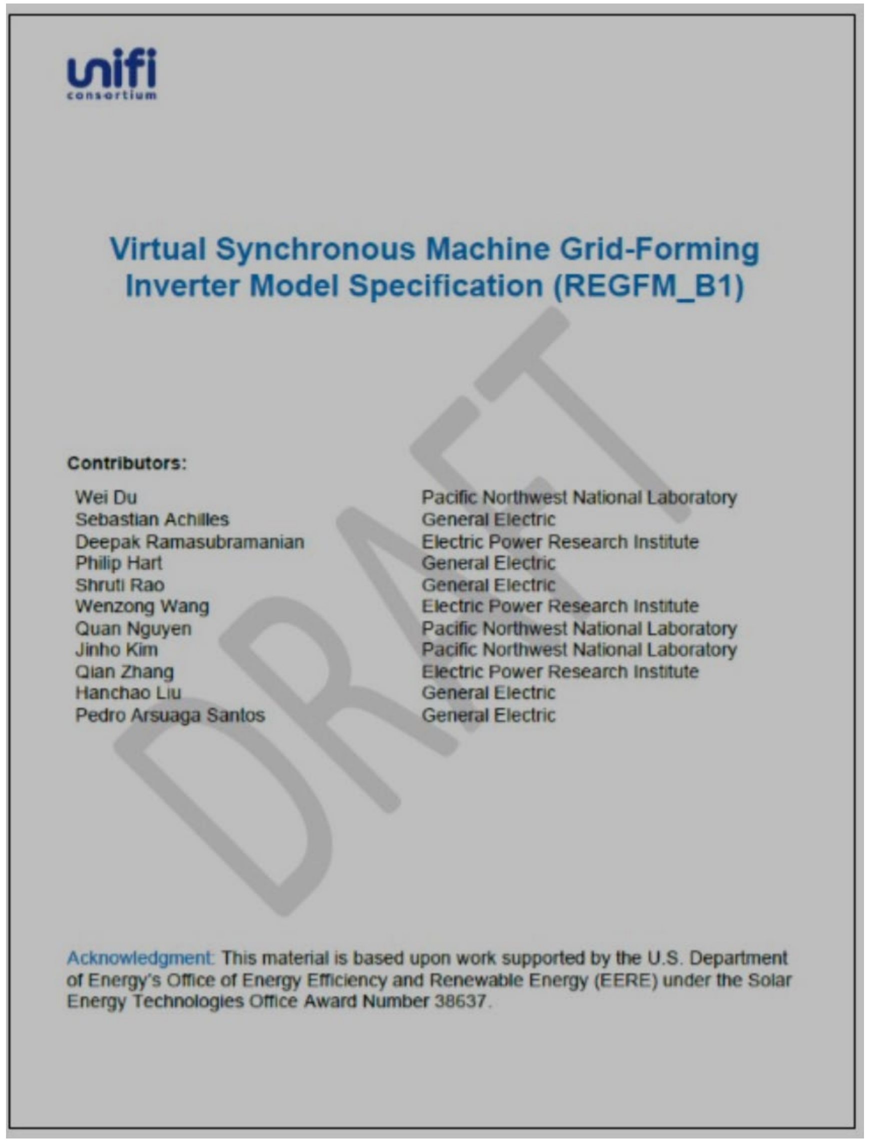
- Five participating IAB members
  - Emanuel E. Bernabeu (PJM)
  - John Paul Skeath (NERC)
  - Song Wang (PGE)
  - Asher Steed (BC Hydro)
  - Yunzhi Cheng (ERCOT)
- (Done) First meeting on 9/30/2022
- (Done) 2nd meeting on 1/30/2023
- (Done) 3rd meeting in 6/16/2023
- (Done) 4th meeting in 1/19/2024
- In-person review meeting (to be scheduled)

FY24 Task 1 Progresses
Prototype testing REGFM_B1 for Oscillation Study

- Integrated REGFM_B1 model to IEEE 39-bus Model in PSS/E
  - Virtual Synchronous Machine GFM Model
  - Steady-state current limiting function
  - Transient current limiting function
  - Grid contingency testing



Simulated results (active power and frequency) by Task 1 team



unifi consortium

Virtual Synchronous Machine Grid-Forming Inverter Model Specification (REGFM_B1)

DRAFT

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Pedro Arsuaga Santos	General Electric

Acknowledgment: This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Solar Energy Technologies Office Award Number 38637.

Wei Du, Deepak Ramasubramanian, 2023 September WECC MVS presentation. https://www.wecc.org/_layouts/15/WopiFrame.aspx?sourcedoc=/Administrative/Du,%20W.,%20and%20Ramasubramanian,%20D.,%20-%20MVS%20-%20Virtual%20Syncrhonous%20Machine%20Grid-Forming%20Inverter%20Model_REGFM_B1.pdf&action=default&DefaultItemOpen=1

FY24 Task 2 Highlights & Progresses
Integrating MTDC and IBRs & Controller Design

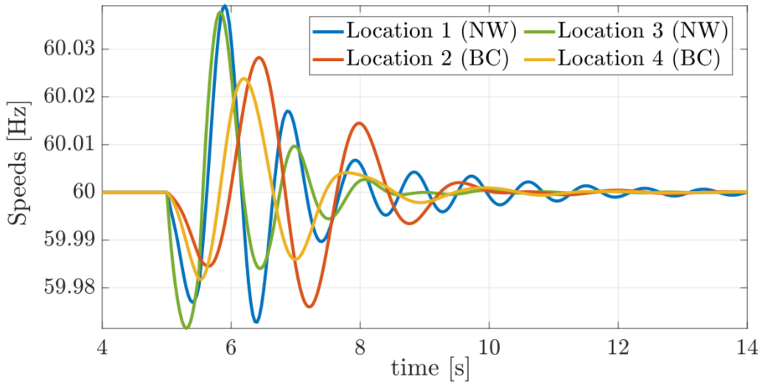


Fig. 2. Generator speeds for the Chief Joseph dynamic brake insertion event.

TABLE I
SUMMARY OF MODAL ANALYSIS

Modal Frequency	Damping Ratio	Mode Shape
0.72 Hz	15 %	British Columbia *vs.* Pacific Northwest
0.93 Hz	18 %	Montana *vs.* Rest of the System
0.84 Hz	19 %	Western Arizona *vs.* Southern California *vs.* Rest

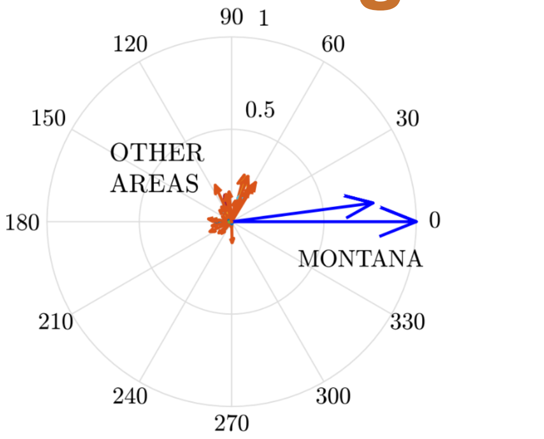


Fig. 5. Shape of the Montana mode estimated from the Colstrip event.

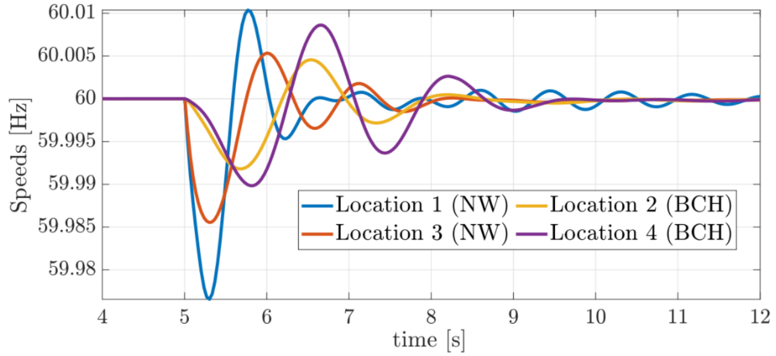


Fig. 3. Generator speeds for CGS inverter trip event.

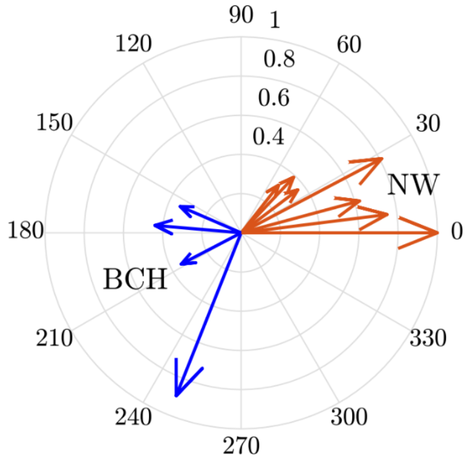


Fig. 4. Shape of the BC-NW mode estimated from the Chief Joseph event.

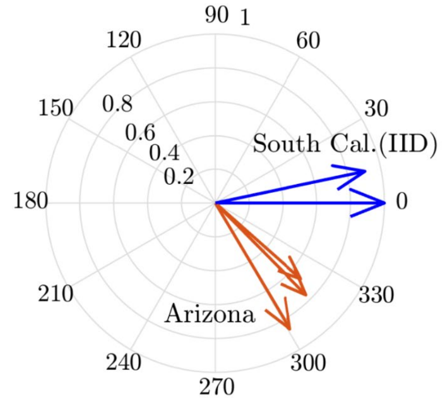
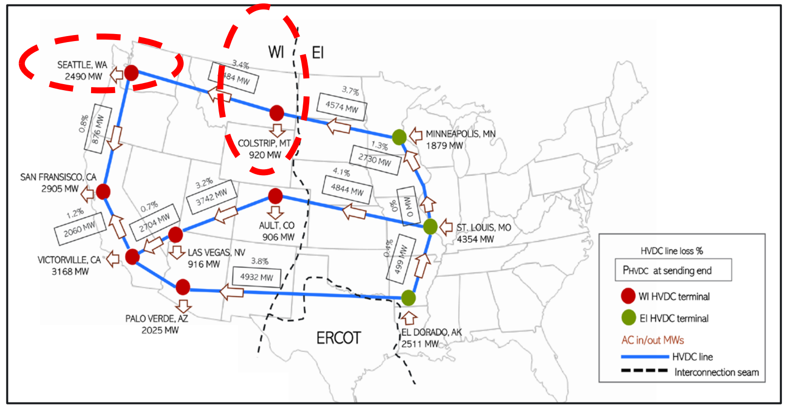


Fig. 6. Shape of the Arizona-Southern California mode estimated from the Palo Verde event.

[Ref] Chatterjee K., S. Nekkalapu, M.A. Elizondo, H. Mahmood, and X. Fan. "Inter-Area Oscillations in Western Interconnection with High Renewable Energy Penetration and MTDC Macrogrid Configuration." 2024 IEEE PES General Meeting (accepted). PNNL-SA-192117.



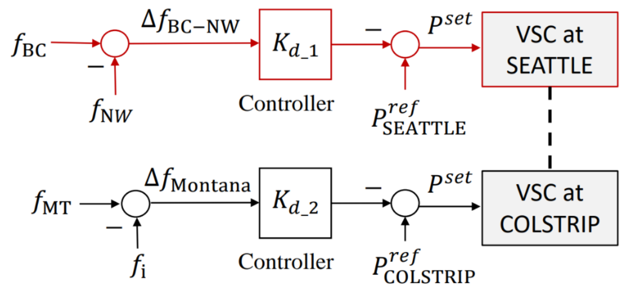


Fig. 7. Modulating the active power set-point at Seattle and Colstrip MTDC terminals for damping the BC-NW and Montana modes, respectively.

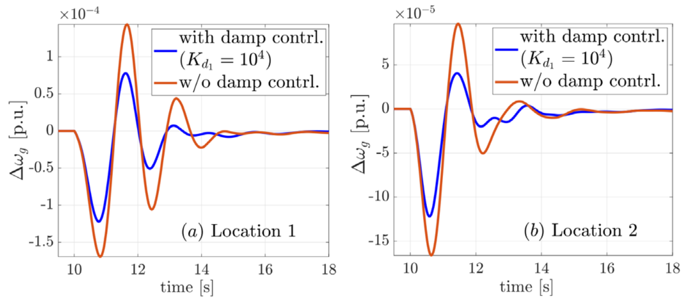
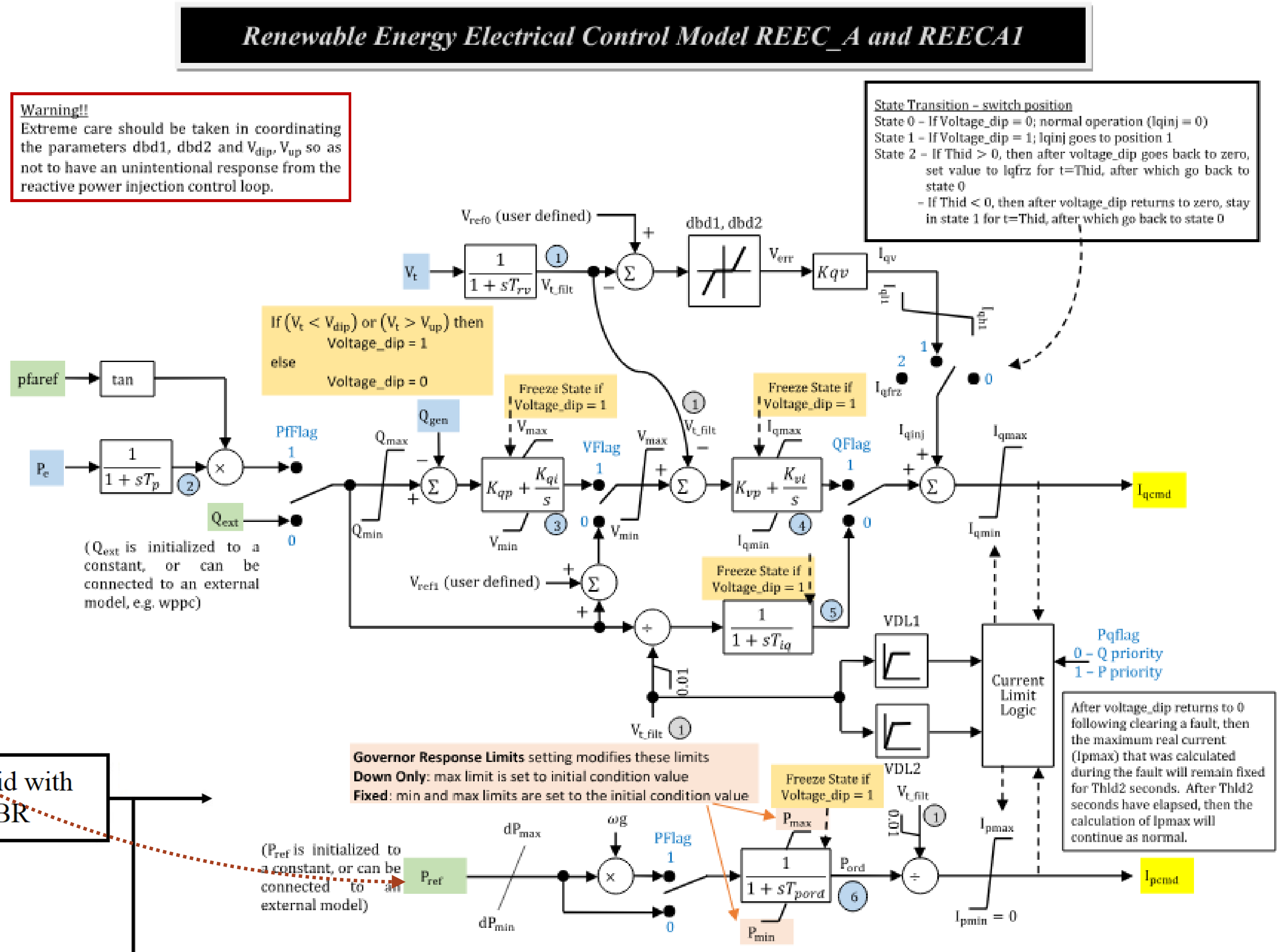


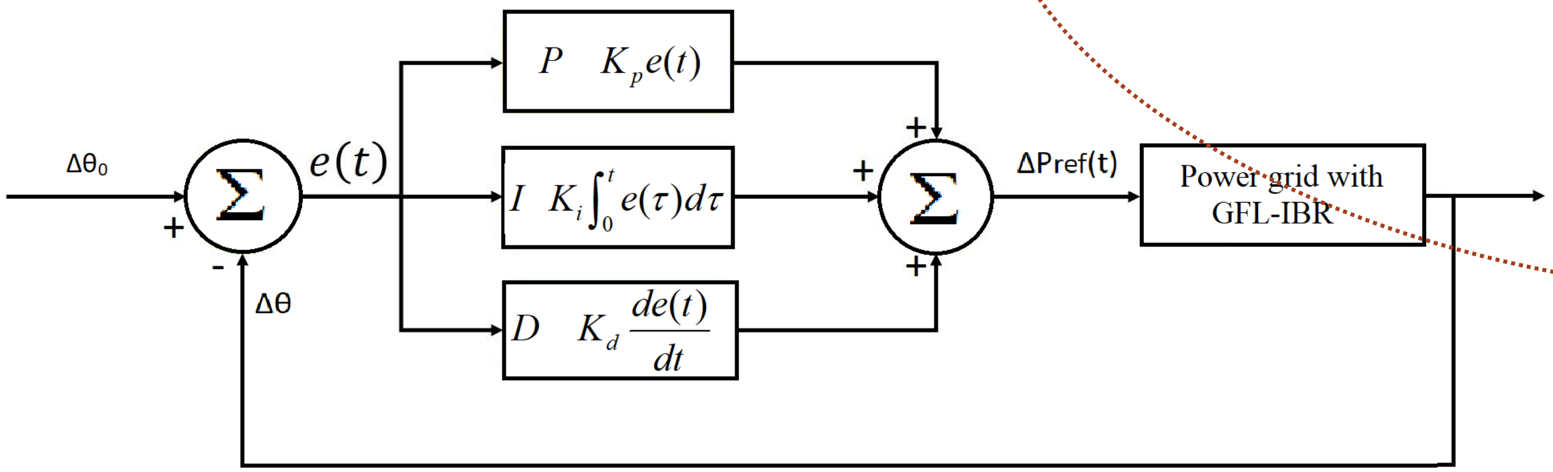
Fig. 8. The generator speeds from two different locations in BC, both with and without the damping control action.

Grid Following IBR Damping control Implementation

- Control Pref in the diagram through the following law:
- Pref=Pref0+ΔPref
- The ΔPref is adjusted by phase angles difference (Δθ) between selected buses, shown in the following diagram

Exciter REEC_A and REECA1



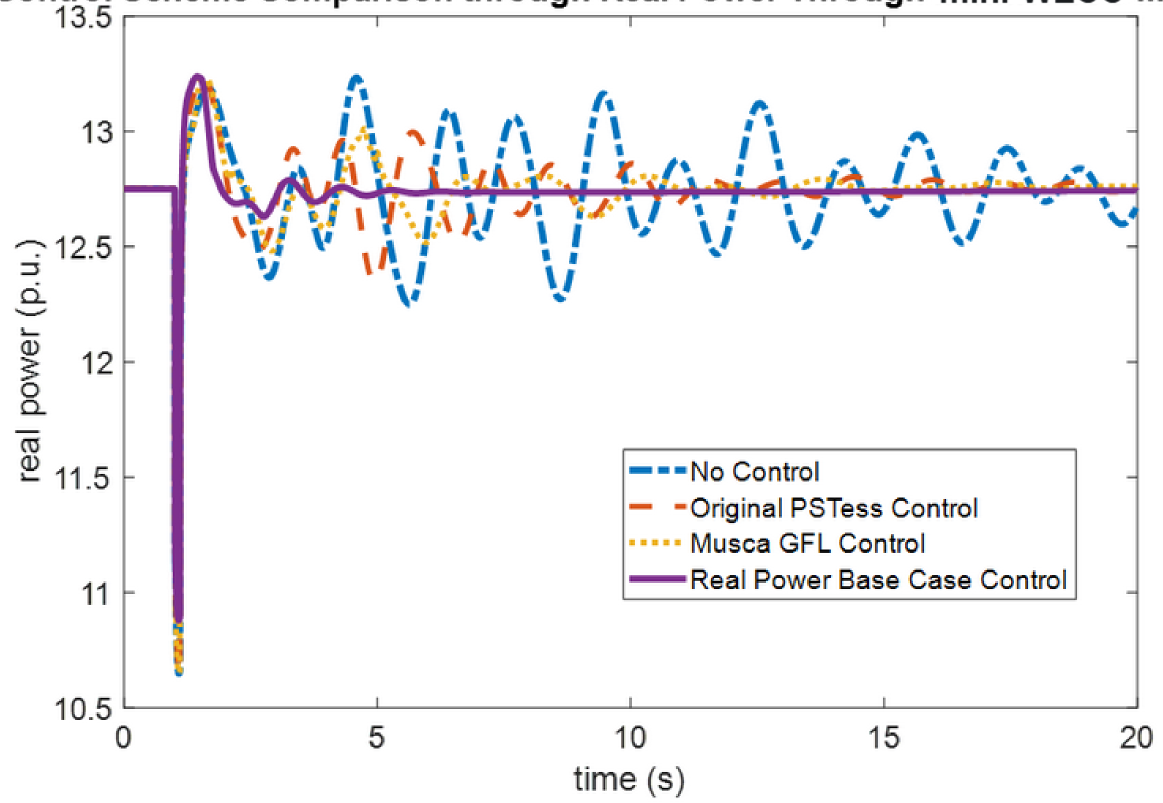


[*] PowerWorld, REECA1 Model

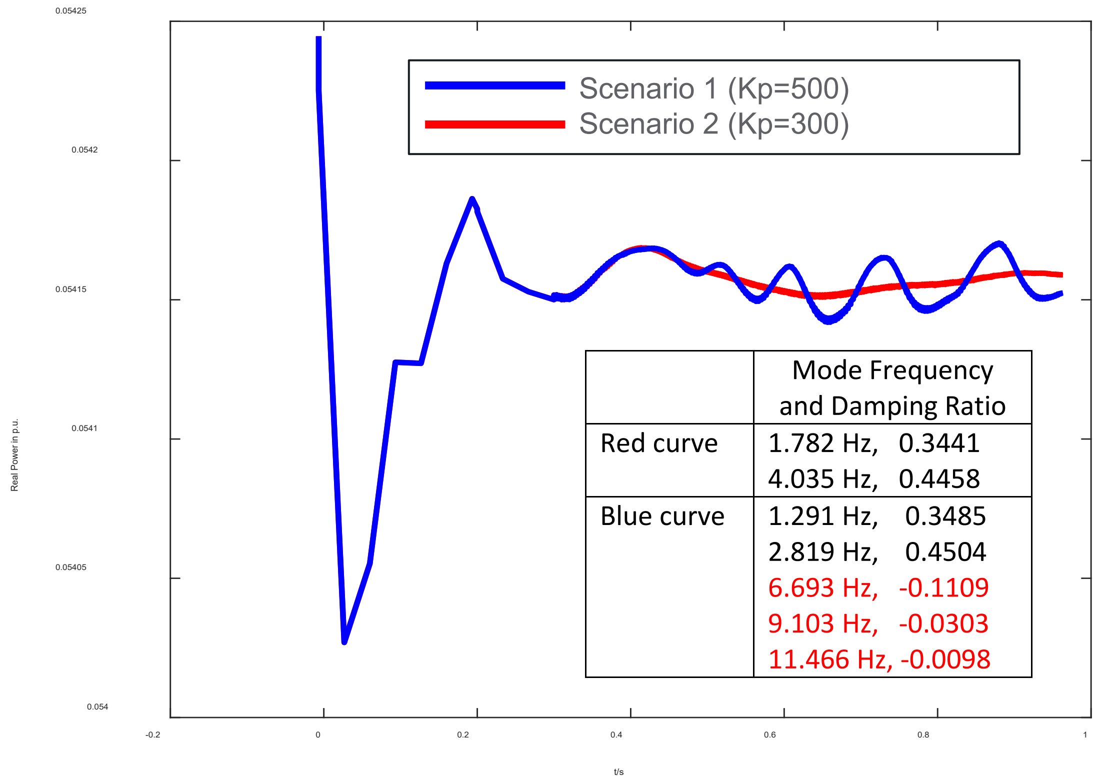
FY24 Task 3 Highlights and progress
Damping control design for single GFL IBR

- Evaluated impacts of additional control to increase the damping ratio of the wide-area oscillations in the mini-WECC system.
- Evaluated impacts of additional control to increase the damping ratio of the wide-area oscillations in the full WECC system (20% GFL IBR) through commercial software PSSE.

Control Scheme Comparison through Real Power Through mini-WECC line #13



Tight Coupling between the Damping Ratio of Real Power Oscillation and Controller Parameter in Full WECC Model



[*] PSTess GFL control. Available online: https://github.com/sandialabs/snl-pstess
[**] Musca GFL control. Musca, Rossano, et al., "Power system oscillations with different prevalence of grid-following and grid-forming converters." Energies 15, no. 12 (2022): 4273

FY24 Task 4 Highlights & Progress

- On Nov. 30, 2023, Prof. Dan Trudnowski attended the Oscillation Analysis Working Group (OAWG) meeting sponsored by WECC.
- He presented our plans for analyzing 2020-2023 WECC-wide PMU data to assess the system modes.
  - Details on what data the team desired.
  - Discussed how we will use the analyses results to update WECC's "***Modes of Inter-Area Power Oscillations in the Western Interconnection***" document.
  - WECC officials updated the OAWG members on the process they are using, to allow Dr. Jim Follum from PNNL and Prof. Trudnowski to obtain the data. This includes official permission from all participating utilities.
- On April 30, 2024, the team learned that there was significant progress on WECC approval and related data sharing agreement. More updates will be provided when available.

FY24 Task 1 Progresses
Industry Guidelines on Modeling Hybrid Power Plants

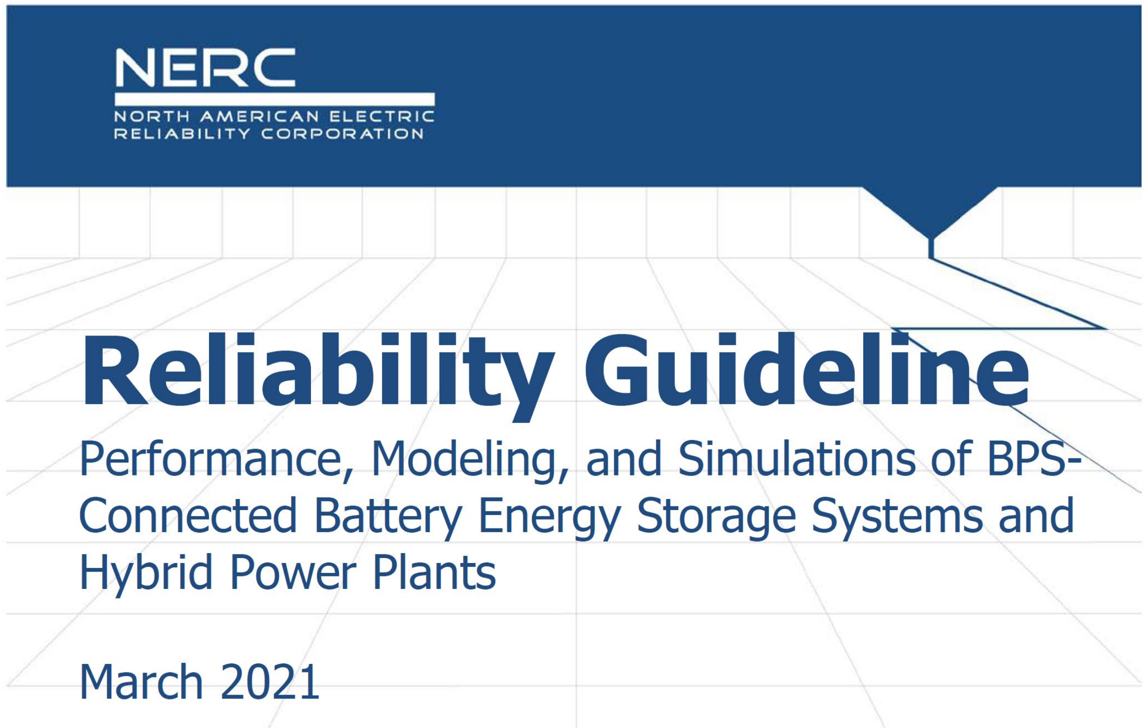
- References used by PNNL team


WECC

Modeling Renewable Energy/Battery Energy Storage System
Hybrid Power Plants

WECC REMWG

August 27, 2020


NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Reliability Guideline

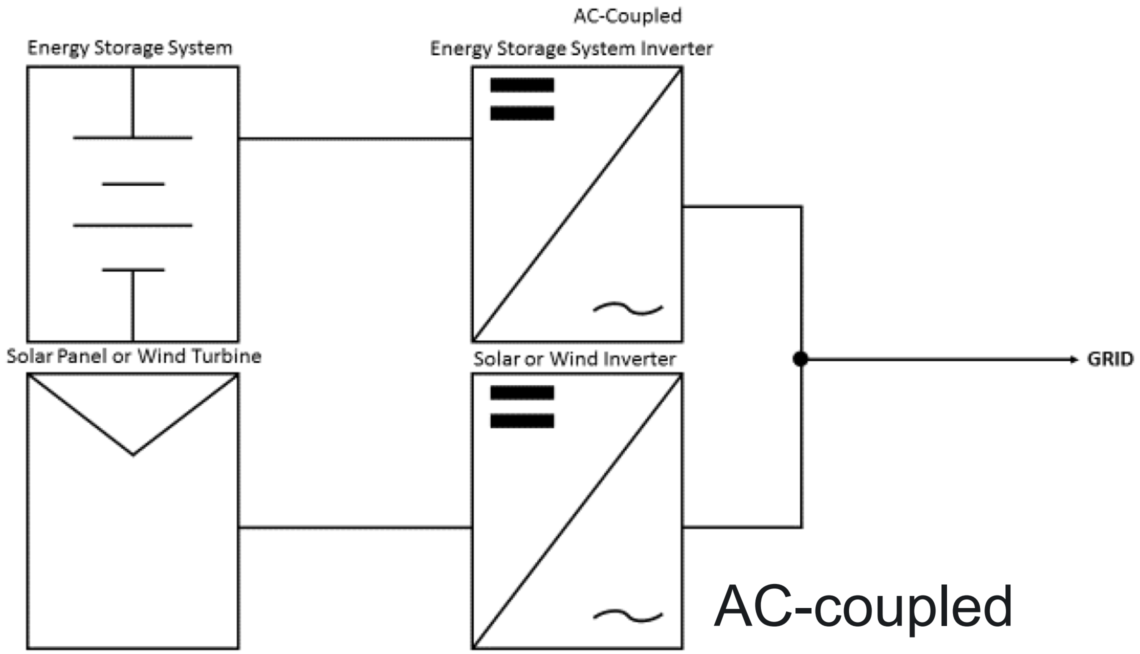
Performance, Modeling, and Simulations of BPS-Connected Battery Energy Storage Systems and Hybrid Power Plants

March 2021

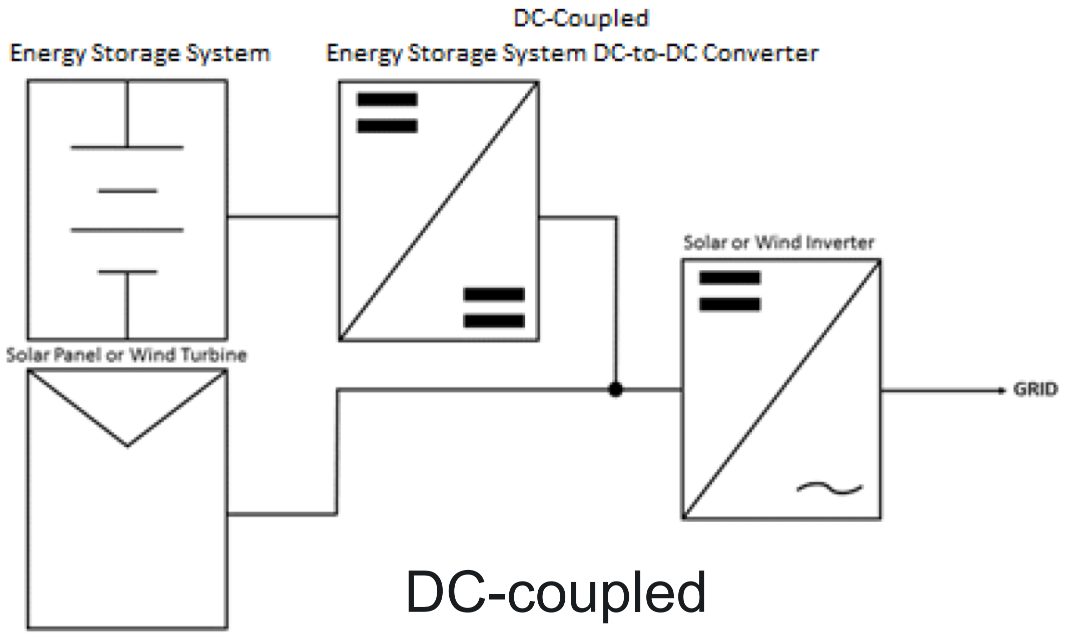
[*] WECC REMWG white paper. Available online. https://www.wecc.org/Administrative/WECC%20White%20Paper%20on%20Modeling%20Hybrid%20Power%20Plant.pdf
[**] NERC Reliability Guideline. Available online. https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Reliability_Guideline_BESS_Hybrid_Performance_Modeling_Studies_.pdf

FY24 Task 1 Progresses
Industry Guidelines on Modeling Hybrid Power Plants (cont'd)

- Definition of hybrid power plants:
  - Co-located
  - Coordinated operation: especially in voltage control
- Two main configurations:
  - AC-coupled (separated converters): more flexible with existing storage, RES models
  - DC-coupled (common converter): avoid power clipping, requiring locations to be close



AC-coupled

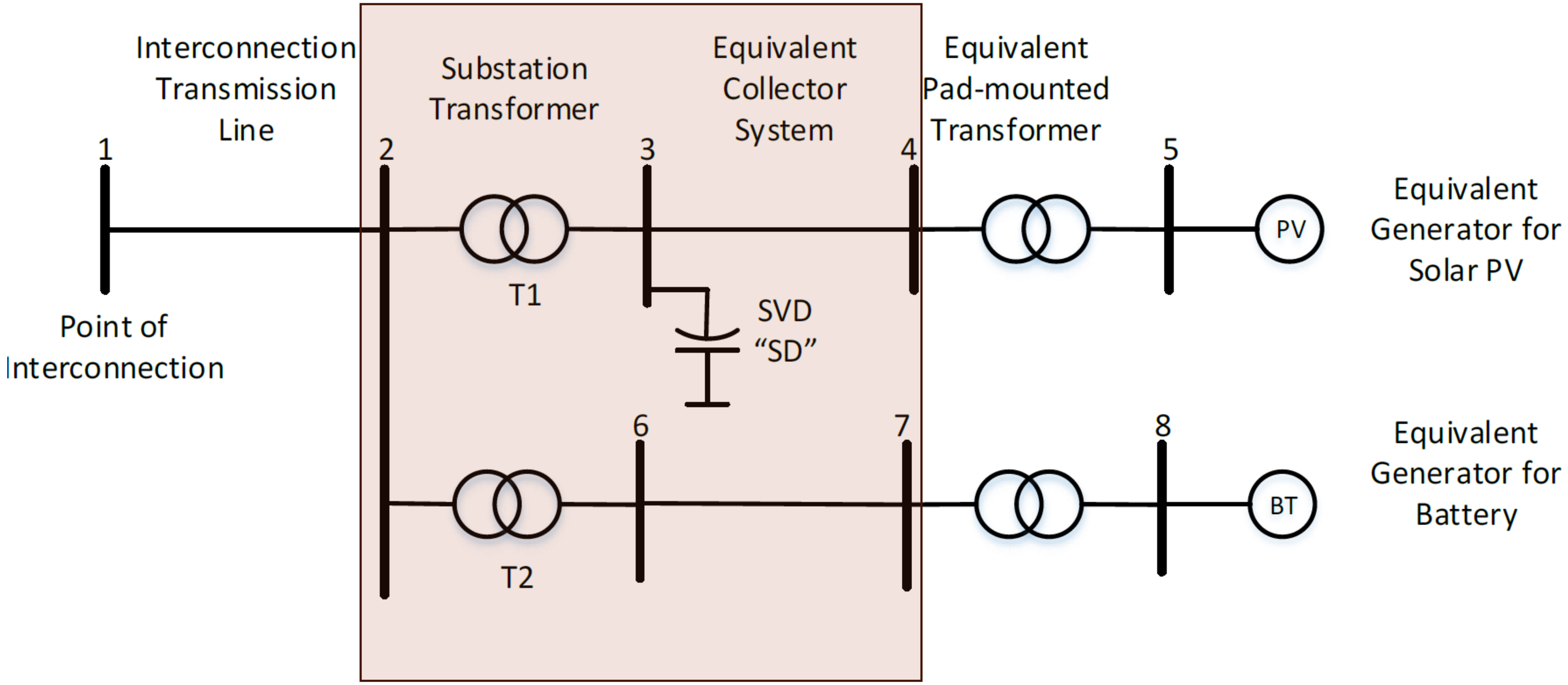


DC-coupled

[*] WECC REMWG white paper. Available online. https://www.wecc.org/Administrative/WECC%20White%20Paper%20on%20Modeling%20Hybrid%20Power%20Plant.pdf

FY24 Task 1 Progresses
Industry Guidelines on Modeling Hybrid Power Plants (cont'd)

- Any plants with rating above 20MVA requires detailed modeling



Note: the actual detailed plant configurations can vary, depending on the voltage ratings at the POIs of the chosen plants to be converted to hybrid power plants in the WECC 2031 HW case

[*] WECC REMWG white paper. Available online. https://www.wecc.org/Administrative/WECC%20White%20Paper%20on%20Modeling%20Hybrid%20Power%20Plant.pdf

FY24 Task 1 Progresses
Exemplar Dynamic model of Hybrid Power Plants

	RES	ES
Plant control	REPCA1	REPCA1
Electrical control	REECA1	REECC1 (PSSE 35) REECCU1 (PSSE 34)
Generator/Converter model	REGCA1	REGCA1

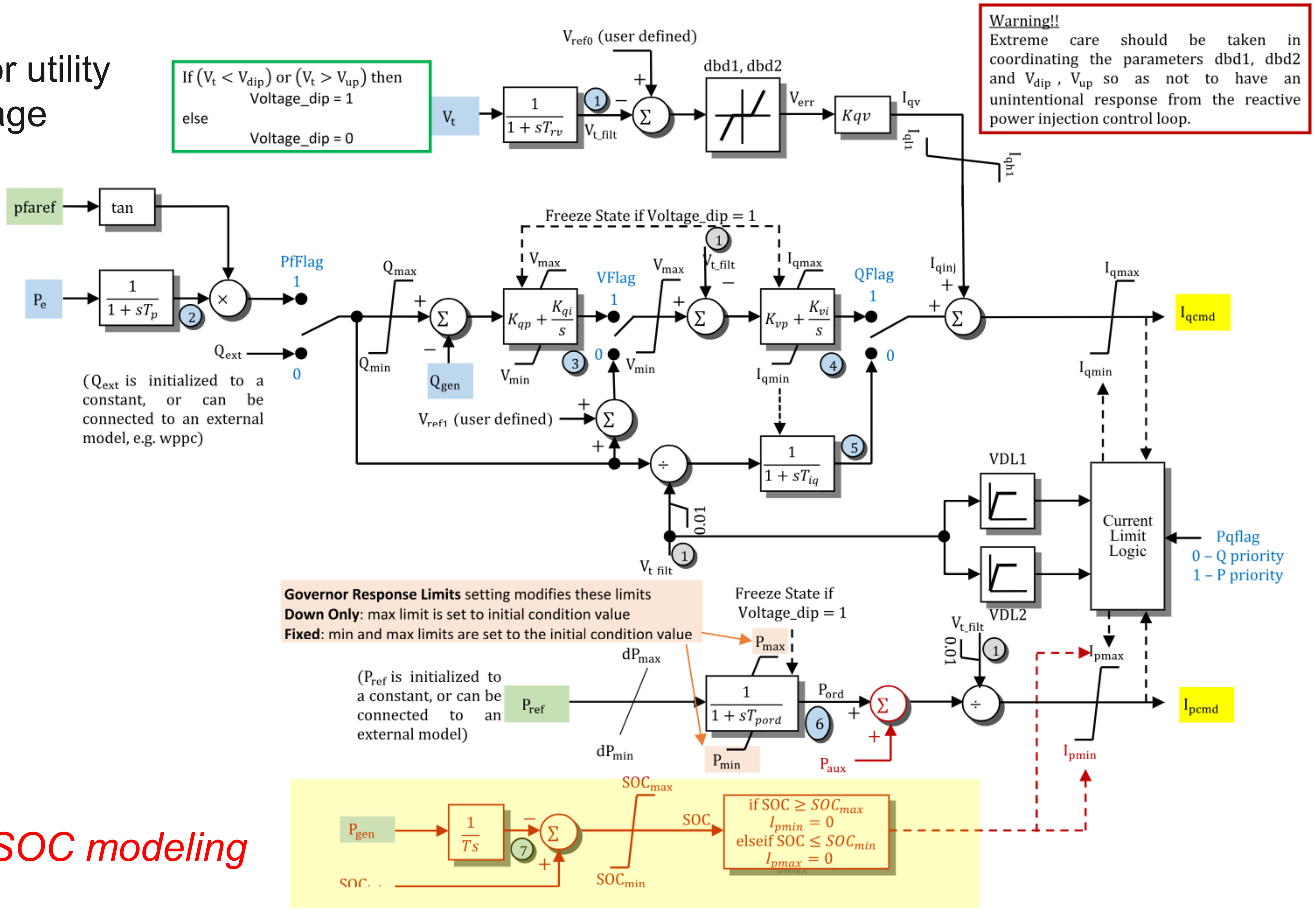
* RES: renewable energy source ES: energy storage

** Dynamic parameters are adopted from existing dynamic model database in the WECC and EI planning cases

Dynamic model of Hybrid Power Plants

REEC_C1/ REEC_CU1

- Electrical control model for utility scale battery energy storage system



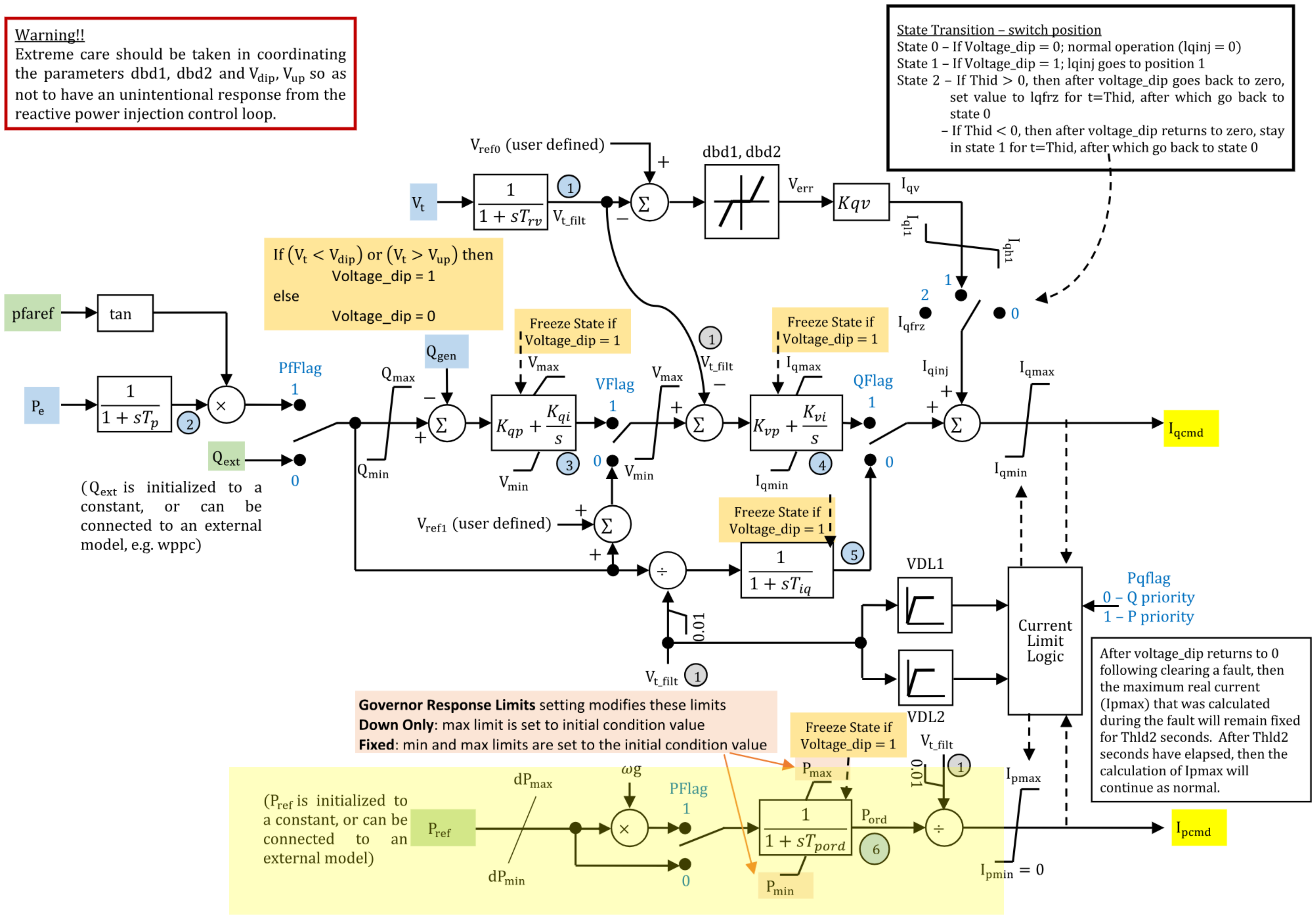
ES SOC modeling

[[*] PowerWorld, REEC_C Model]

Dynamic model of Hybrid Power Plants (cont'd)

REEC_A1:

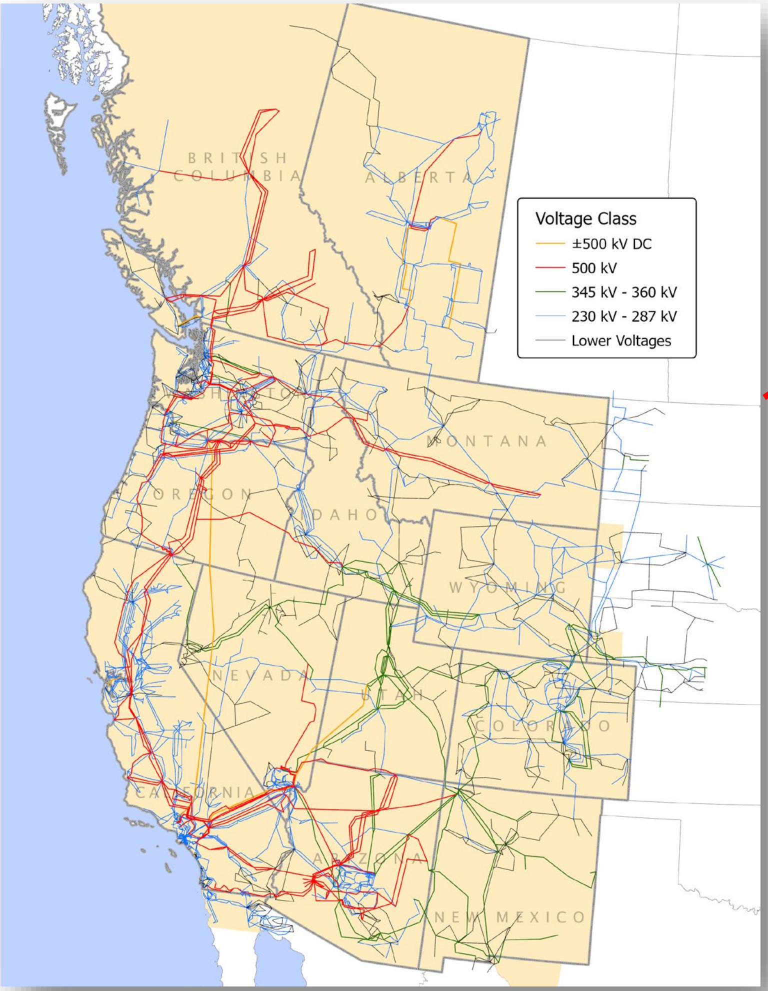
- Generic renewable electrical control model
- Electrical control model for large scale PV

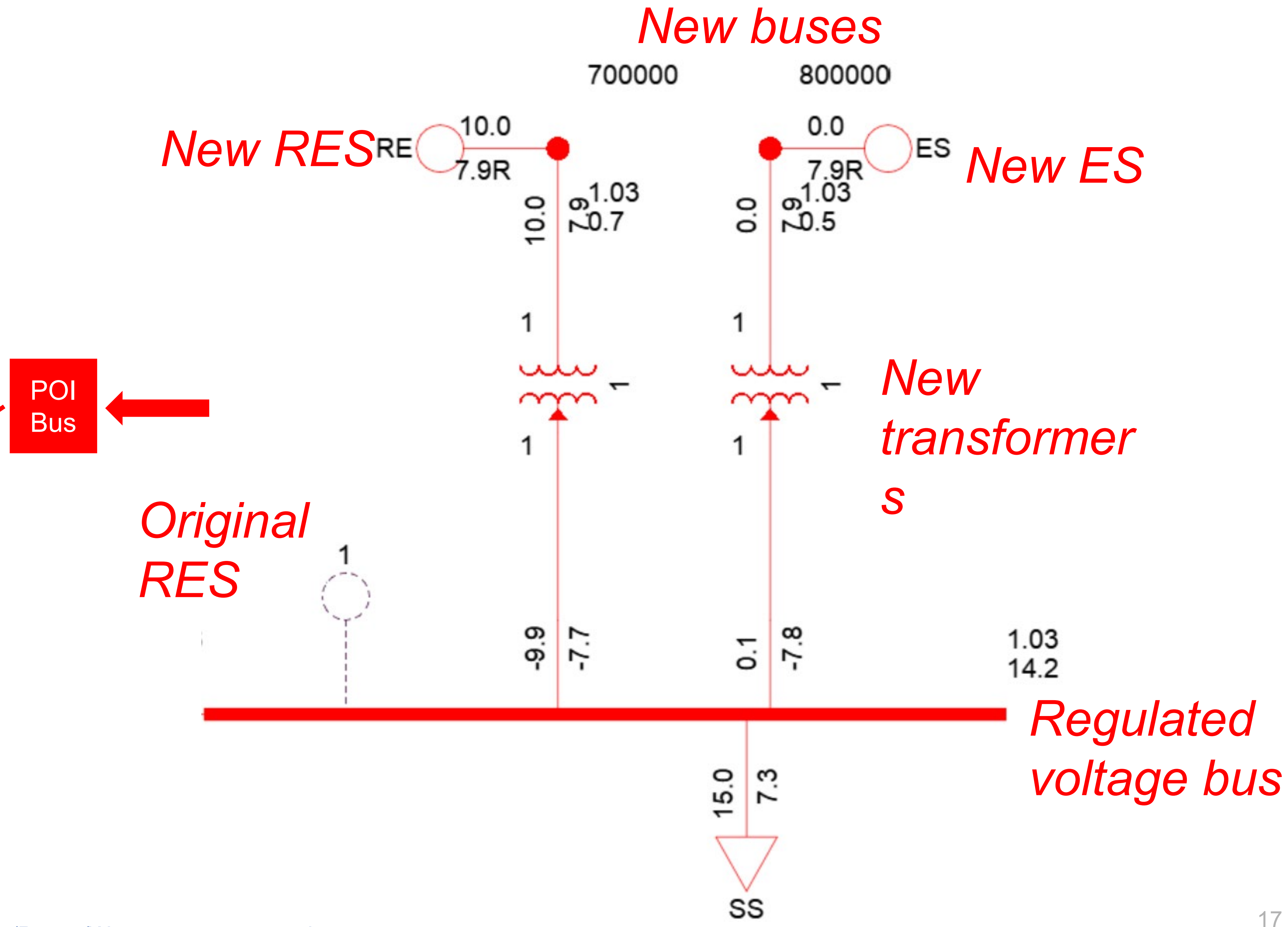


[*] PowerWorld, REEC_A and REEC_A1 Model

FY24 Task 1 Progresses
WECC 2031 Heavy-Winter Model with HPPs

- Example of how we replace an existing RES by HPP

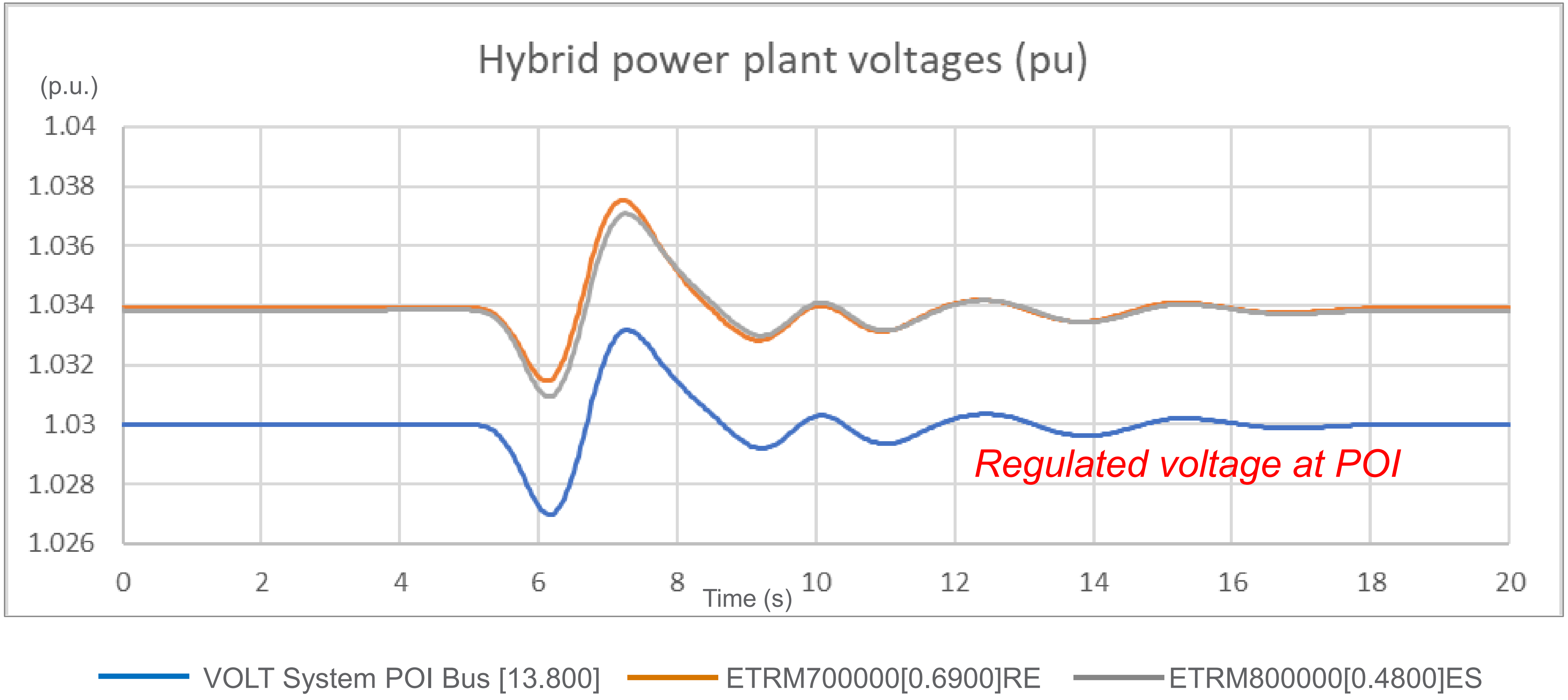




WECC Transmission Introduction,
see https://www.wecc.org/epubs/StateOfTheInterconnection/Pages/Western-Interconnection.aspx

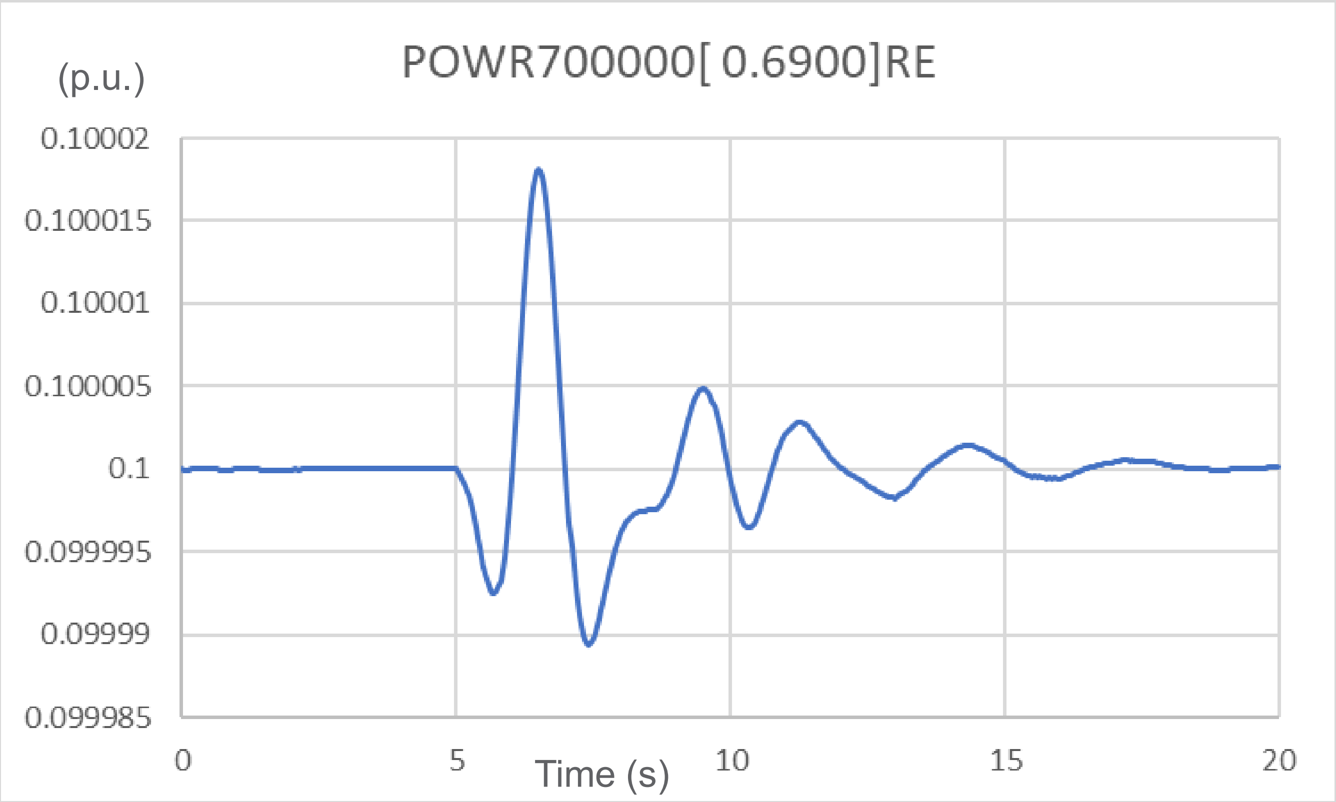
FY24 Task 1 Progresses
WECC 2031 Heavy-Winter Model with HPPs (cont'd)

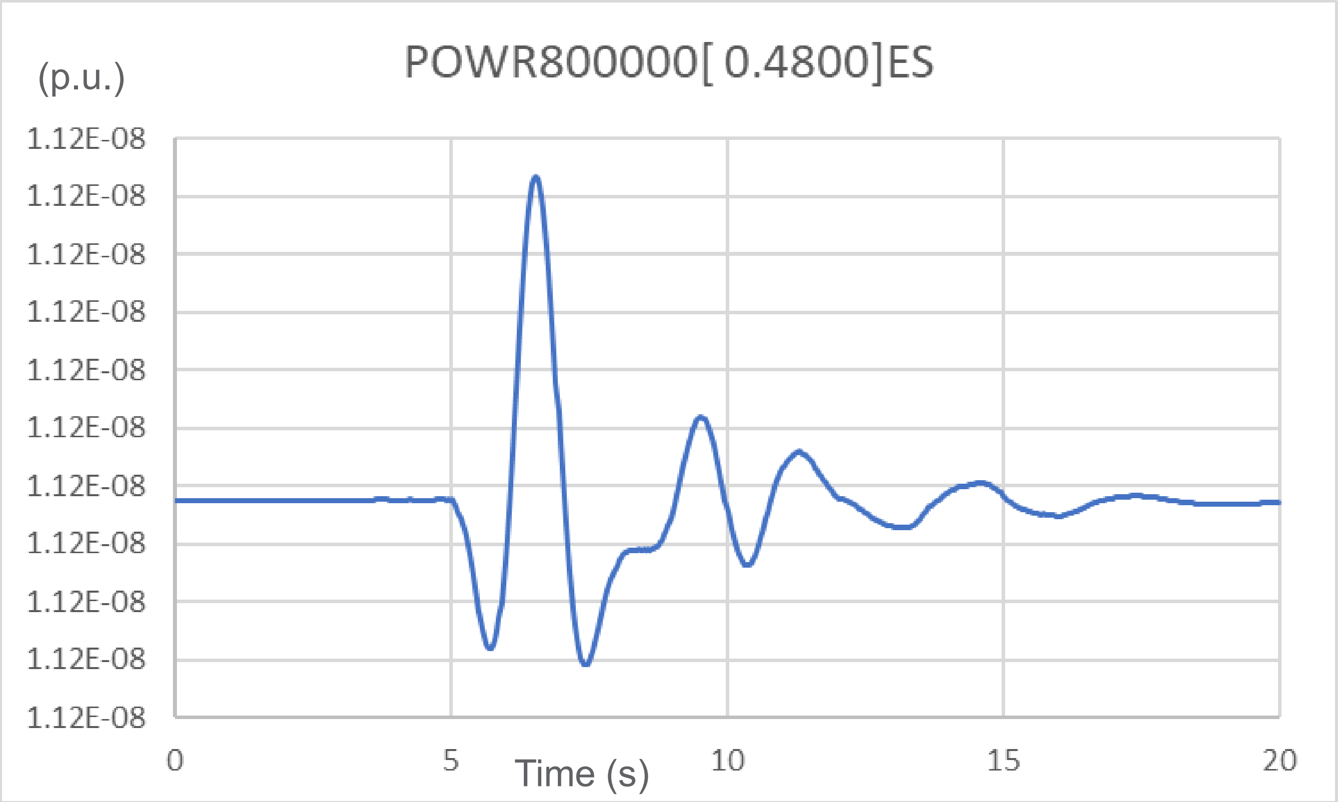
- Dynamic simulation results



FY24 Task 1 Progresses
WECC 2031 Heavy-Winter Model with HPPs (cont'd)

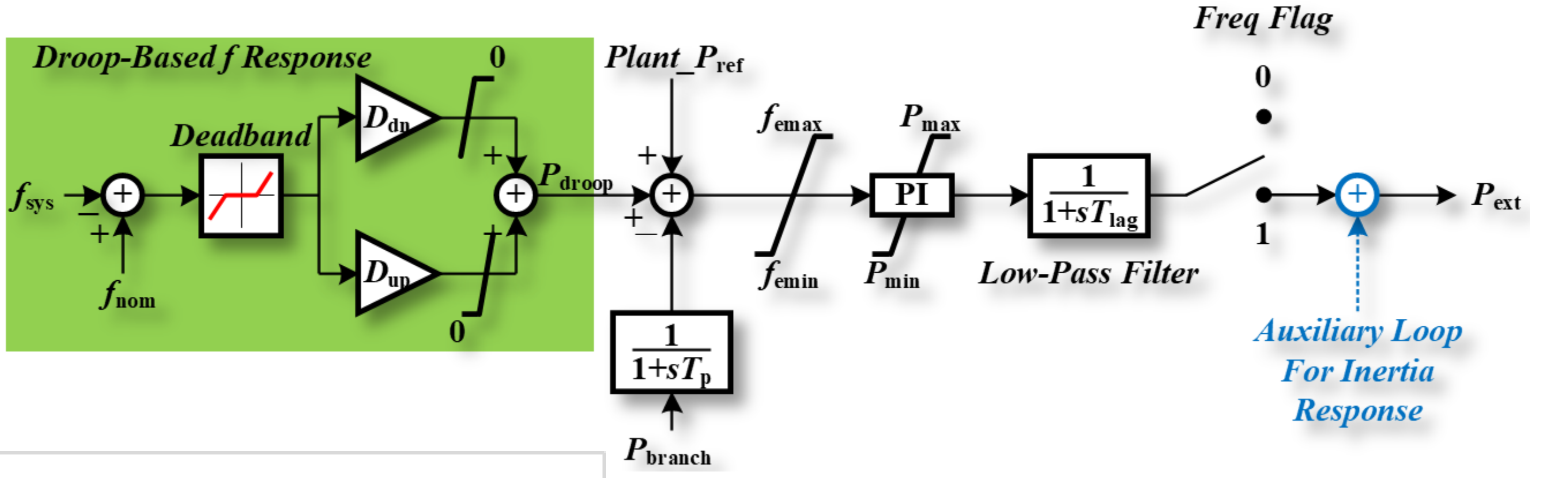
- Dynamic simulation results (cont'd)



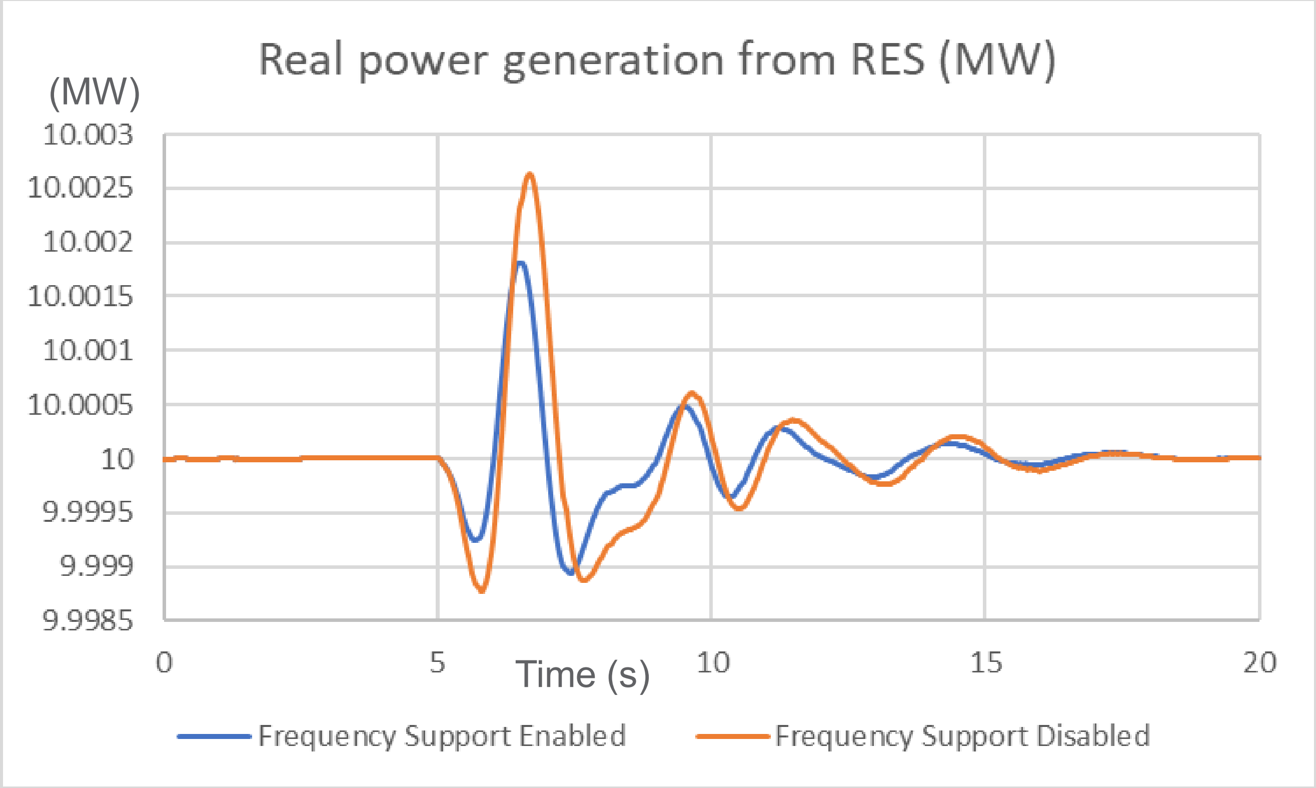


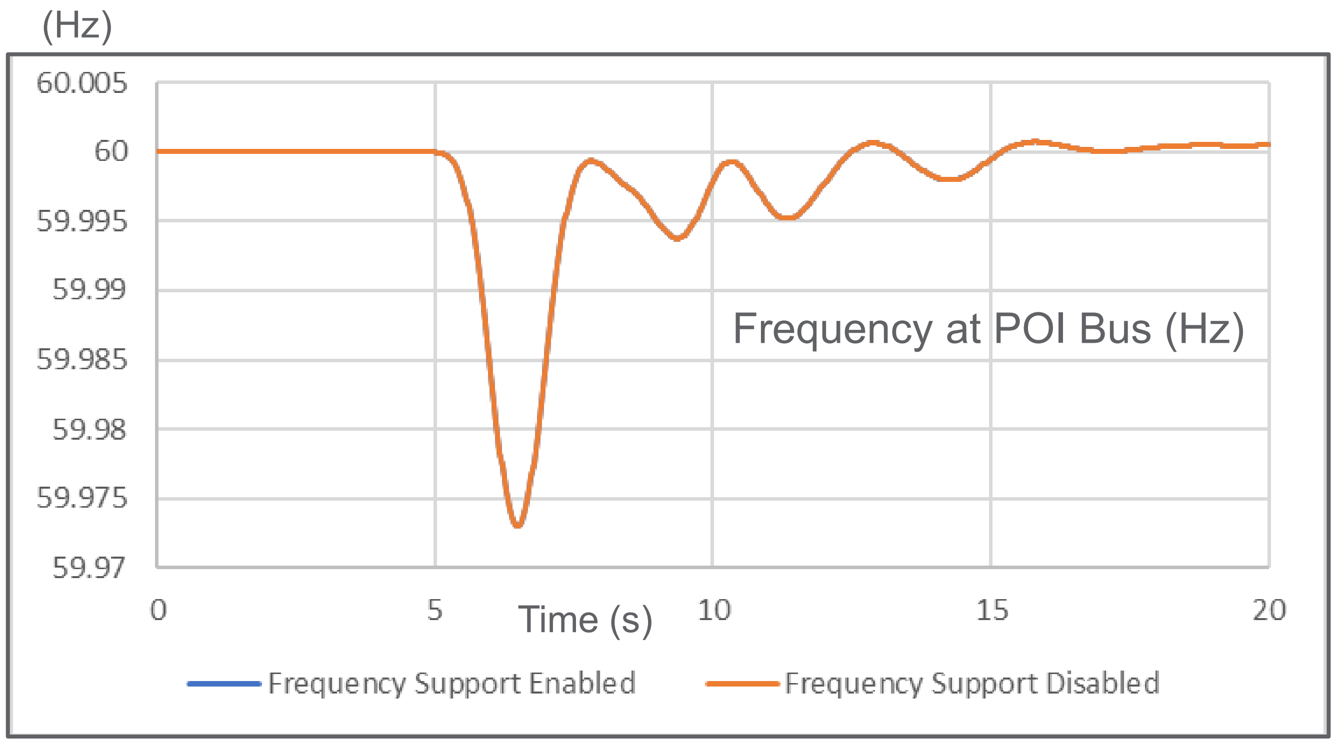
FY24 Task 1 Progresses
WECC 2031 Heavy-Winter Model with HPPs (cont'd)

- Frequency support function in REPCA1 model of the RES



(Figure credited to PNNL)





FY24 Task 1 Progresses
WECC 2031 Heavy-Winter Model with HPPs (cont'd)

- Next steps:
  - Continue to add and test more hybrid power plants
    - Current observations: initialization issues when adding more hybrid plants
    - Plant parameters need to be tuned
  - Study frequency support capability of these hybrid plants

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Thank you

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