Pacific Northwest
NATIONAL LABORATORY

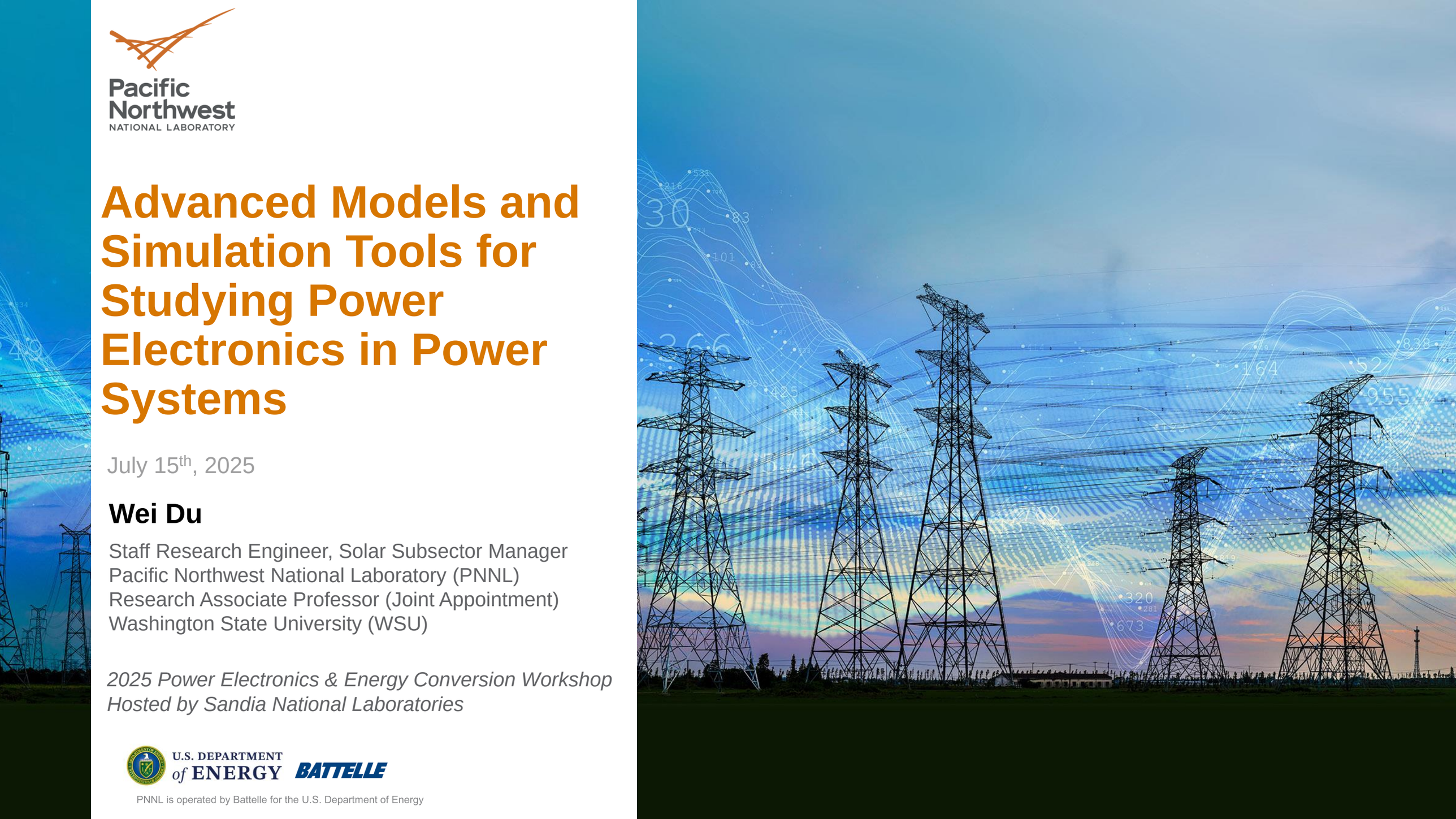
Advanced Models and Simulation Tools for Studying Power Electronics in Power Systems

July 15th, 2025

Wei Du

Staff Research Engineer, Solar Subsector Manager
Pacific Northwest National Laboratory (PNNL)
Research Associate Professor (Joint Appointment)
Washington State University (WSU)

2025 Power Electronics & Energy Conversion Workshop
Hosted by Sandia National Laboratories

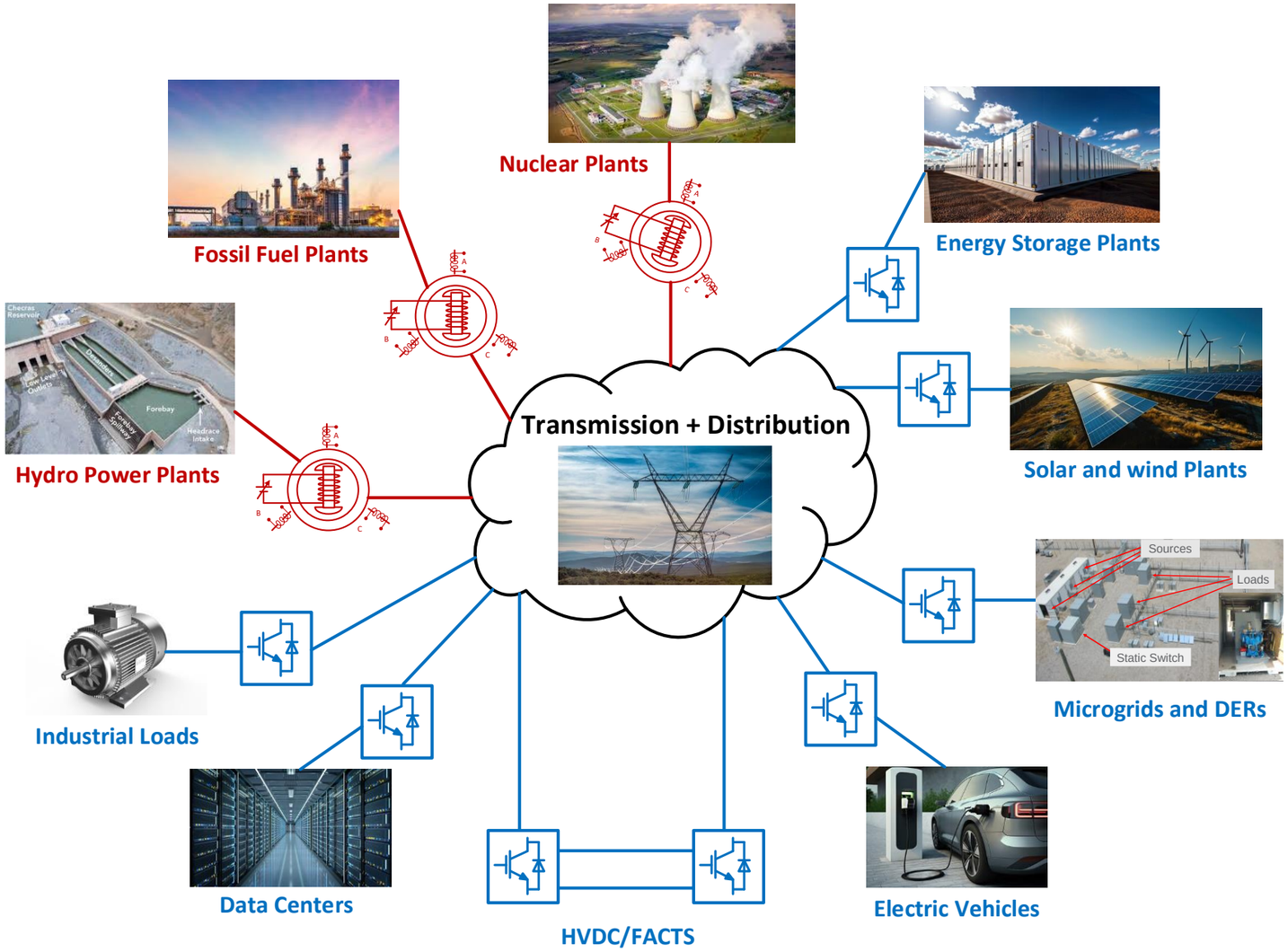


U.S. DEPARTMENT of ENERGY BATTELLE

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

Power Electronics in Power Systems

- Power electronics plays a vital role in the power system across generation, transmission, distribution, and loads
- Power electronics changes the physics of power systems, bringing new challenges and opportunities
- *Accurate and efficient power electronics component models and simulation tools are critical to study the influence of power electronics on the grid at the system level*



Outline

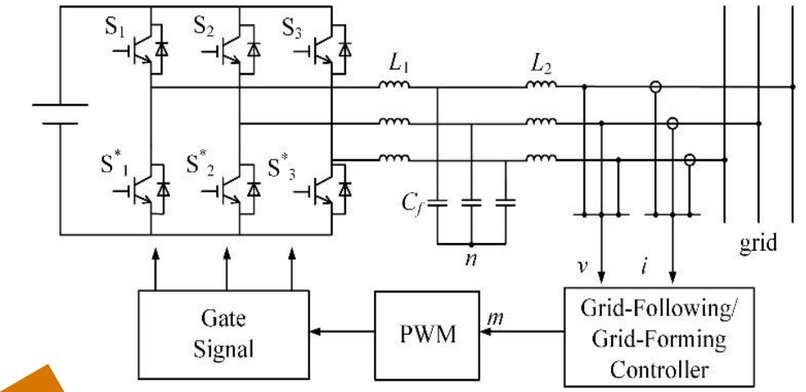
- WECC Standard Library Grid-Forming Inverter Models
- Open-Source Simulation Tool for Studying Distribution System Transients
- Summary and Future Work

WECC Standard Library Grid-Forming Inverter Models

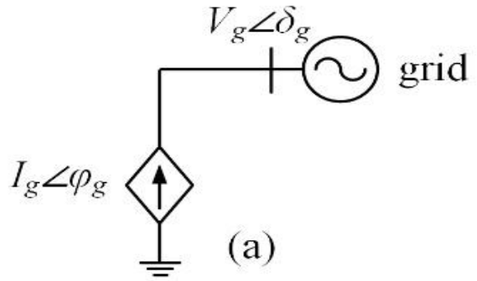
This work is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under Solar Energy Technology Office (SETO) Award Number 38637. The views expressed herein do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

IBR Models in Power System Simulation Tools

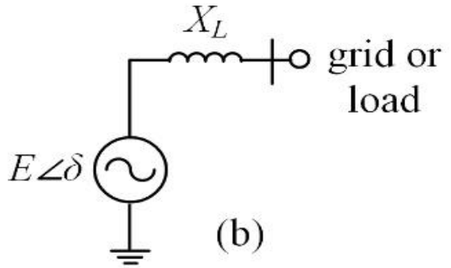
- There are already well-established grid-following inverter-based resource (IBR) models in commercial power system transient stability simulation tools such as PSS/E, PSLF, PowerWorld, TSAT, etc.
- *However, before we initiated this work, there were no grid-forming inverter (GFM) models in those tools*



Voltage-Sourced Inverter



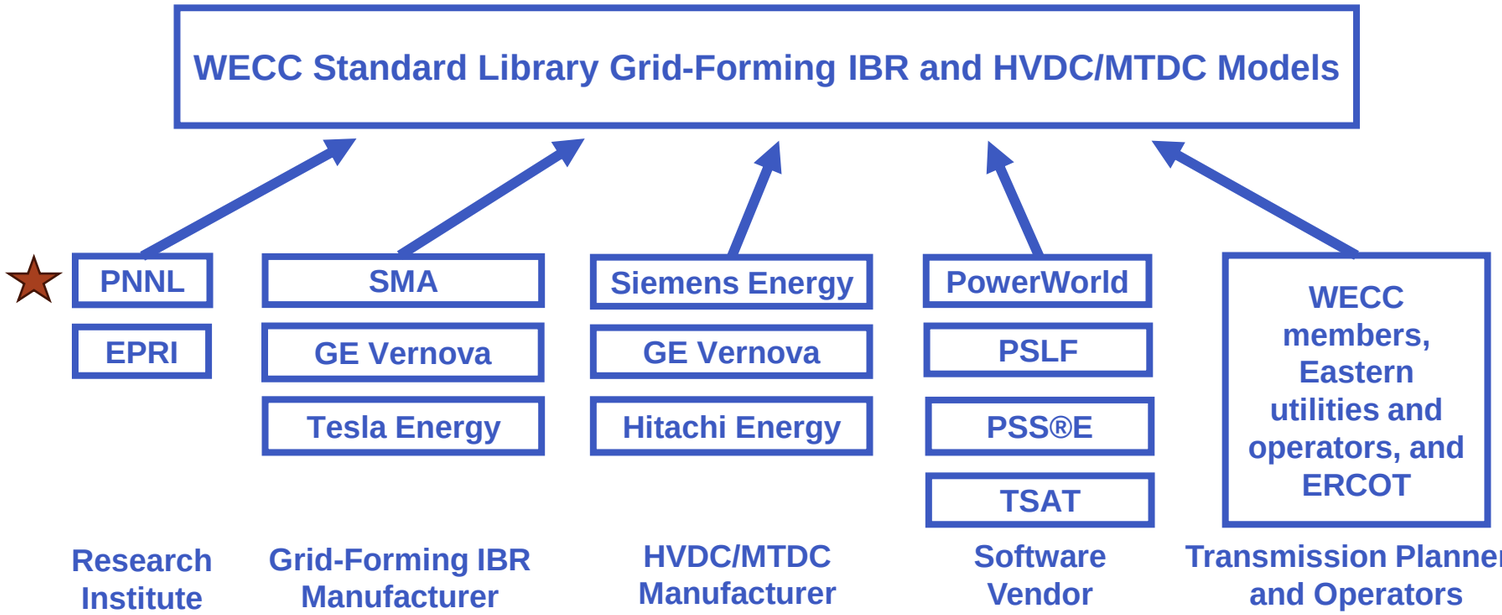
Grid-Following (≈Current Phasor)

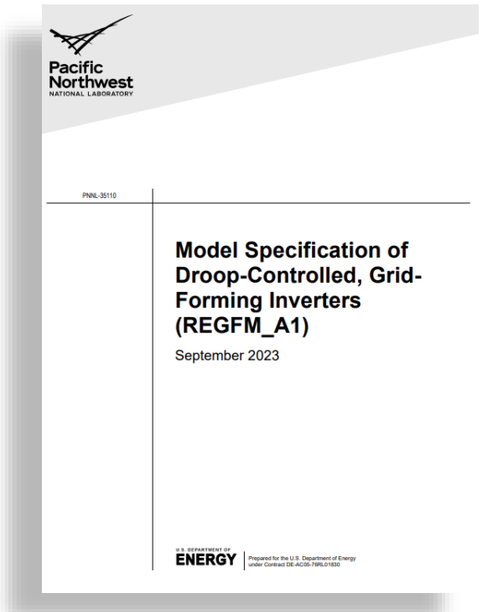


Grid-Forming (≈Voltage Phasor)

WECC Standard Library Grid-Forming Inverter Models

- PNNL is leading the development of WECC standard library GFM models in collaboration with major manufacturers, software vendors, and planners over the past five years funded by DOE UNIFI consortium.
- The development of HVDC/MTDC standard library models started in Jan. 2025




Pacific Northwest NATIONAL LABORATORY

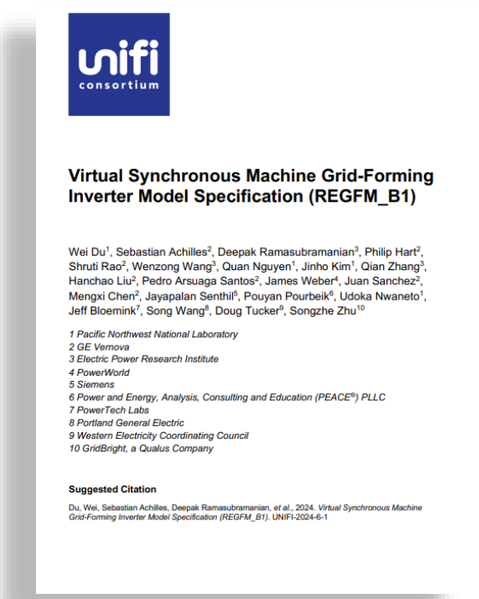
PNNL-35110

Model Specification of Droop-Controlled, Grid-Forming Inverters (REGFM_A1)

September 2023

U.S. DEPARTMENT OF ENERGY | Prepared for the U.S. Department of Energy under Contract DE-AC05-76RL01830

REGFM_A1


unifi consortium

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

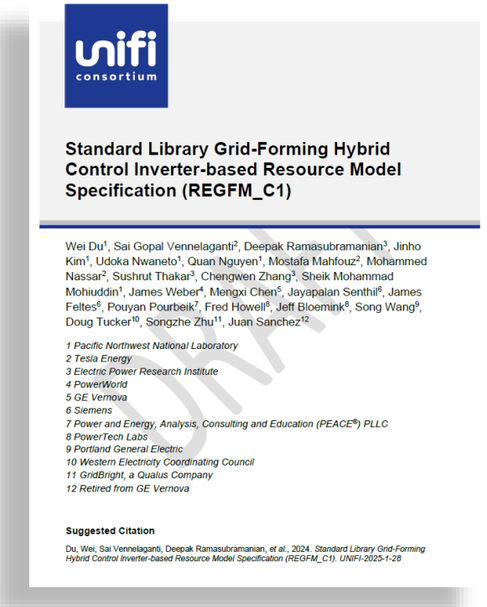
Wei Du[1], Sebastian Achilles[2], Deepak Ramasubramanian[3], Philip Hart[2], Shruti Rao[2], Wenzong Wang[3], Quan Nguyen[1], Jinho Kim[1], Qian Zhang[3], Hanchao Liu[2], Pedro Arsuaga Santos[2], James Weber[4], Juan Sanchez[2], Mengxi Chen[4], Jayapalan Senthil[5], Pouyan Pourbeik[6], Udoka Nwaneto[1], Jeff Bloemink[7], Song Wang[8], Doug Tucker[9], Songzhe Zhu[10]

1 Pacific Northwest National Laboratory
2 GE Vernova
3 Electric Power Research Institute
4 PowerWorld
5 Siemens
6 Power and Energy, Analysis, Consulting and Education (PEACE®) PLLC
7 PowerTech Labs
8 Portland General Electric
9 Western Electricity Coordinating Council
10 GridBright, a Qualus Company

Suggested Citation

Du, Wei, Sebastian Achilles, Deepak Ramasubramanian, *et al.*, 2024. *Virtual Synchronous Machine Grid-Forming Inverter Model Specification (REGFM_B1).* UNIFI-2024-6-1

REGFM_B1


unifi consortium

Standard Library Grid-Forming Hybrid Control Inverter-based Resource Model Specification (REGFM_C1)

Wei Du[1], Sai Gopal Vennelaganti[2], Deepak Ramasubramanian[3], Jinho Kim[1], Udoka Nwaneto[1], Quan Nguyen[1], Mostafa Mahfouz[2], Mohammed Nassar[2], Sushrut Thakar[3], Chengwen Zhang[3], Sheik Mohammad Mohiuddin[1], James Weber[4], Mengxi Chen[5], Jayapalan Senthil[6], James Feltes[6], Pouyan Pourbeik[7], Fred Howell[8], Jeff Bloemink[8], Song Wang[9], Doug Tucker[10], Songzhe Zhu[11], Juan Sanchez[12]

1 Pacific Northwest National Laboratory
2 Tesla Energy
3 Electric Power Research Institute
4 PowerWorld
5 GE Vernova
6 Siemens
7 Power and Energy, Analysis, Consulting and Education (PEACE®) PLLC
8 PowerTech Labs
9 Portland General Electric
10 Western Electricity Coordinating Council
11 GridBright, a Qualus Company
12 Retired from GE Vernova

Suggested Citation

Du, Wei, Sai Vennelaganti, Deepak Ramasubramanian, *et al.*, 2024. *Standard Library Grid-Forming Hybrid Control Inverter-based Resource Model Specification (REGFM_C1).* *UNIFI-2025-1-28*

REGFM_C1


unifi consortium

Standard Library Plant Controller Model Specification for a Grid-Forming Hybrid Control Inverter-based Resource (REPCGFM_C1)

Wei Du[1], Sai Gopal Vennelaganti[2], Deepak Ramasubramanian[3], Jinho Kim[1], Udoka Nwaneto[1], Quan Nguyen[1], Ali Mohammadpour[2], Sarah Walinga[2], Lilan Karunaratne[2], Mostafa Mahfouz[2], Mohammed Nassar[2], Sushrut Thakar[3], Chengwen Zhang[3], Sheik Mohammad Mohiuddin[1], James Weber[4], Mengxi Chen[5], Jayapalan Senthil[6], James Feltes[6], Pouyan Pourbeik[7], Fred Howell[8], Jeff Bloemink[8], Song Wang[9], Doug Tucker[10], Songzhe Zhu[11], Juan Sanchez[12]

1 Pacific Northwest National Laboratory
2 Tesla Energy
3 Electric Power Research Institute
4 PowerWorld
5 GE Vernova
6 Siemens
7 Power and Energy, Analysis, Consulting and Education (PEACE®) PLLC
8 PowerTech Labs
9 Portland General Electric
10 Western Electricity Coordinating Council
11 GridBright, a Qualus Company
12 GE Vernova (retried)

Suggested Citation

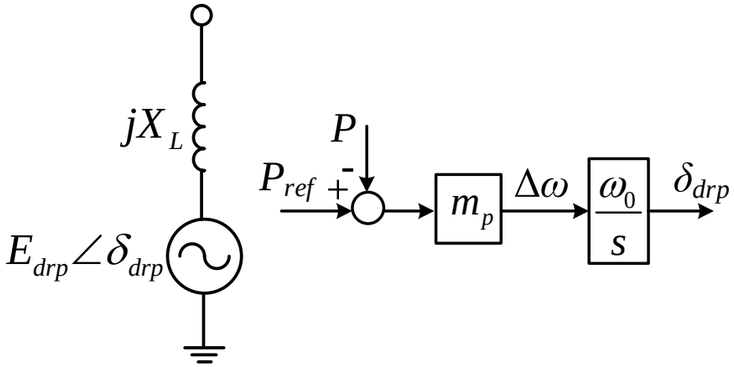
Du, Wei, Sai Vennelaganti, Deepak Ramasubramanian, *et al.*, 2024. Standard Library Plant Controller Model Specification for a Grid-Forming Hybrid Control Inverter-based Resource (REPCGFM_C1). *UNIFI-2025-1-29*

REPCGFM_C1

Key Control Features in Standard Library GFM Models

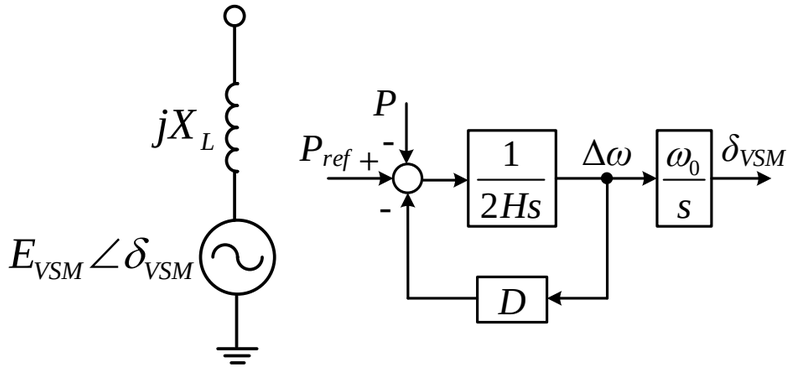
- REGFM_A1 is based on droop control
- REGFM_B1 is based on virtual synchronous machine (VSM) control
- REGFM_C1 is based on GFM + GFL hybrid control
- These models also describe controls for GFMs under various constraints such as *P* and *Q* limiting, current limiting, and fault ride-through

REGFM_A1



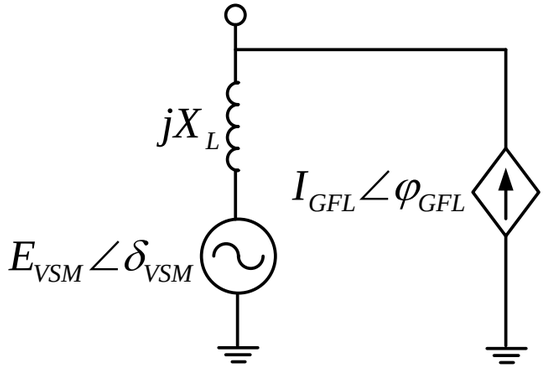
GFM Droop Control

REGFM_B1



GFM VSM Control

REGFM_C1



GFM Hybrid Control
(VSM + GFL)

WECC Standard Library GFM Models in Commercial Tools

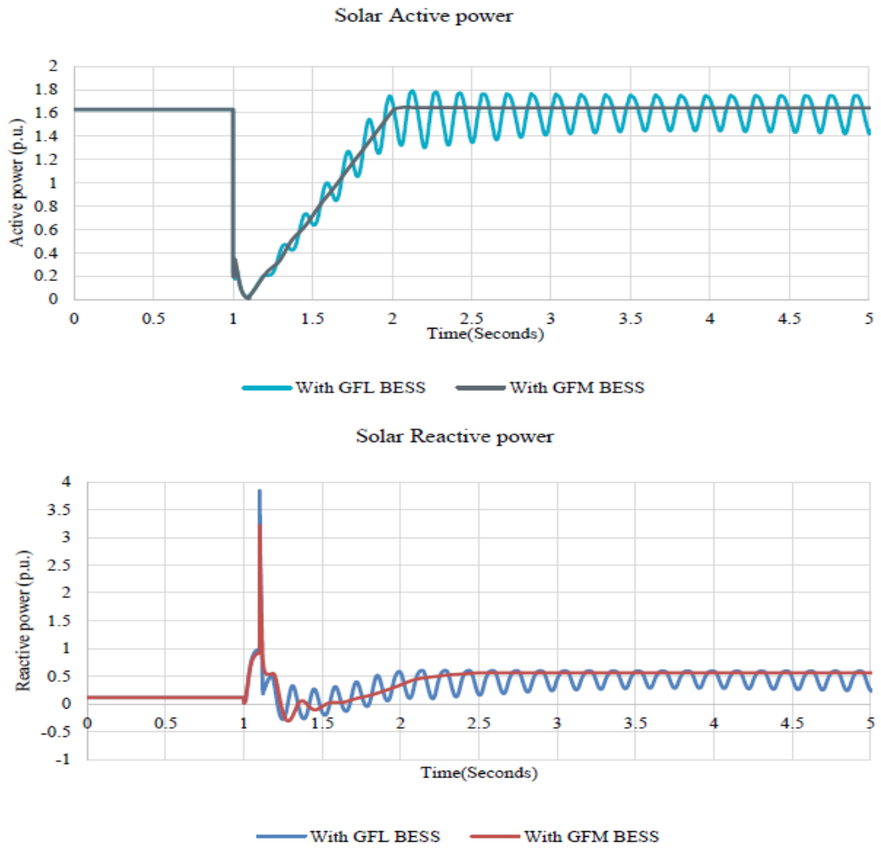
- These models represent the first generation of industry-approved standard library GFM models and have been integrated into leading commercial transient stability simulation tools

	REGFM_A1 (GFM Droop Control)	REGFM_B1 (Virtual Synchronous Machine)	REGFM_C1 and REPCGFM_C1 (GFM Hybrid Control)
Siemens PSS/E	V36.1	V36.1	Implemented
GE PSLF	V23.2.8.2	V23.2.8.2	Implementing
PowerWorld Simulator	V23	V23	V24
Powertech Labs TSAT	V24.1	V24.1	Implemented
DigSilent PowerFactory	V2025	Implementing	Implementing

PSS/E is used by 2,000+ organizations across 140+ countries, PowerWorld is used by 1,000+ organizations across 70 countries, and PowerFactory is used by 2,500+ organizations across 170+ countries, etc.

Case 1: Renewable Integration in Weak Grids

- A local area (138kV) in the ERCOT grid has been identified with stability issue due to weak grid, causing stability issues when integrating renewables
- A GFM BESS model (REGFM_A1) was used to replace the original GFL model. The results in both PSSE and PSCAD tests show stable response for both N 1 and N-1-1 and no stability constraint is needed if the BESS is equipped with proper GFM capability



Stability Improvement of a Weak System [1]

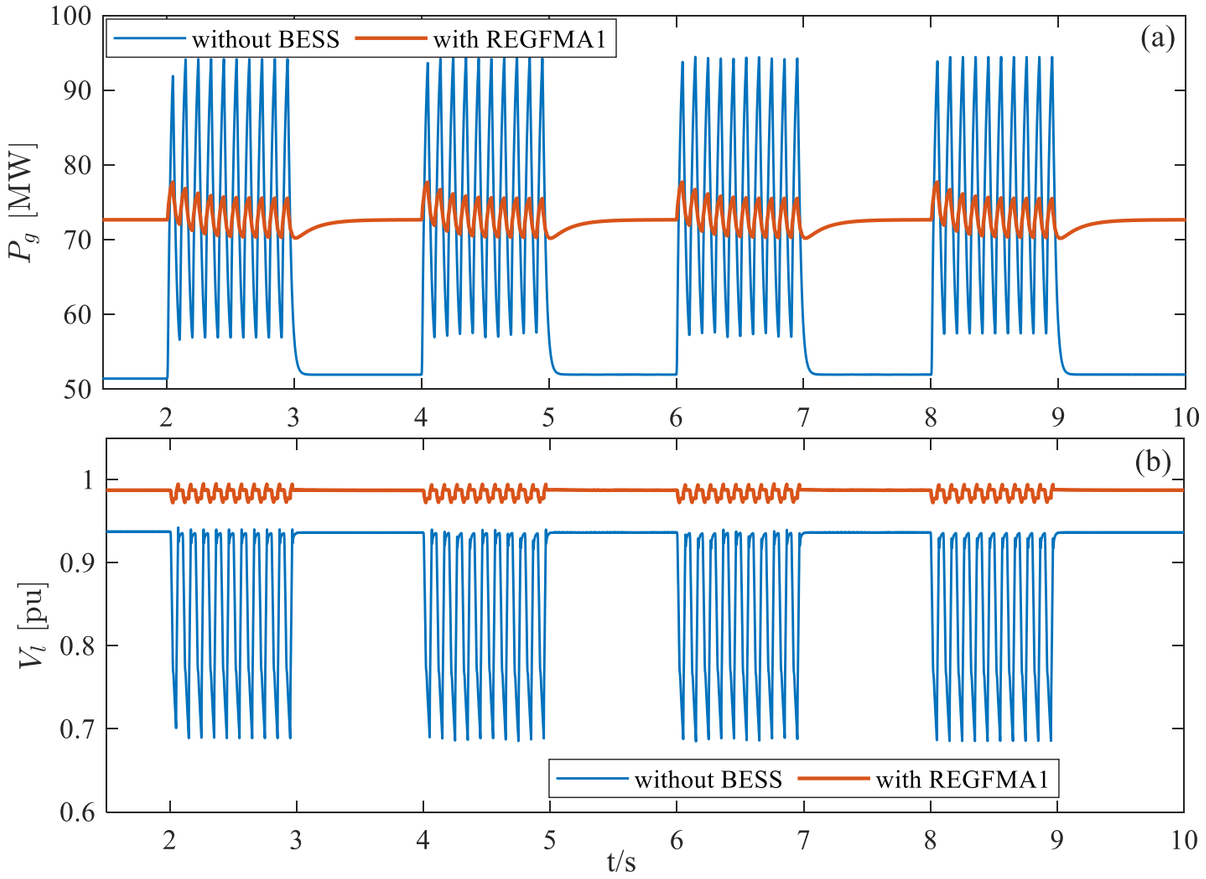
ERCOT Presentation on GFMs

Simulations were conducted by ERCOT engineers on the full ERCOT system with 6,000+ buses and hundreds of generators and IBRs

[1] https://www.ercot.com/files/docs/2023/08/11/GFM_ERCOT_IBRWG%2808112023%29.pdf

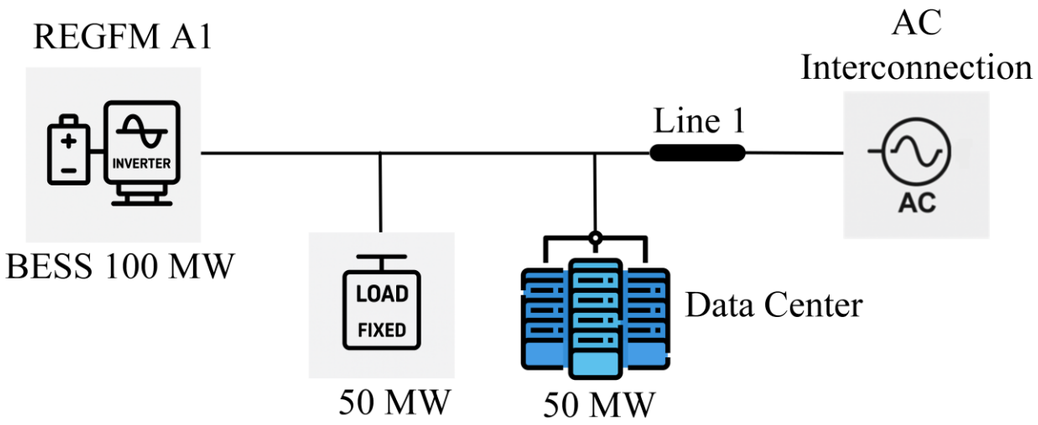
Case 2: Large Electric Load/Data Center Application

- AI training data centers can cause fast load fluctuations (5-30 Hz)
- The GFM BESS can mitigate the load fluctuation and improve the local voltage stability
- Advanced controls can be added on the GFM BESS to further improve the control effect



GFM BESS can mitigate the forced oscillation caused by LELs

SCR=2, load fluctuation frequency: 10 Hz



One-line diagram of the studied system

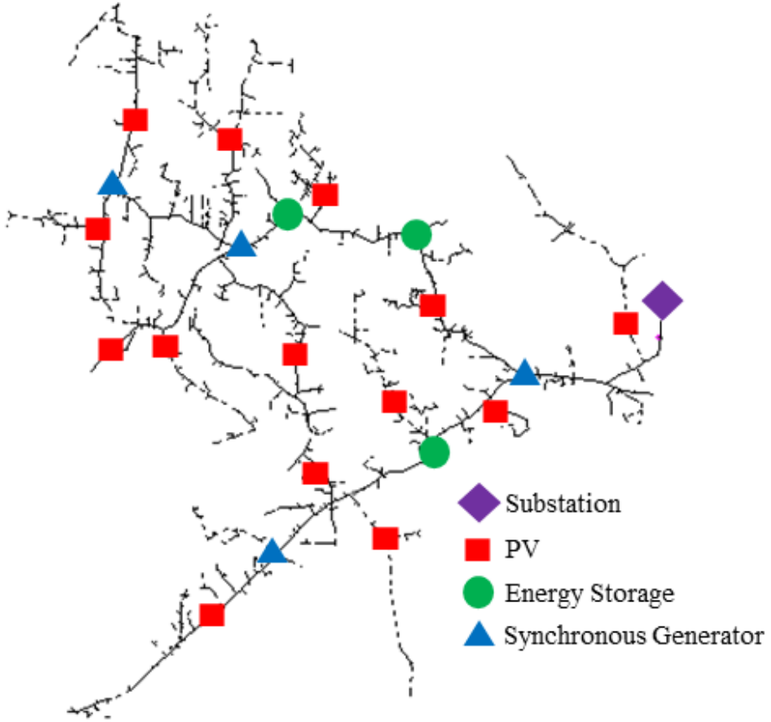
Open-Source Simulation Tool for Studying Distribution System Transients

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 38453. The views expressed herein do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

Simulating the Transients and Dynamics of Distribution Systems with a high penetration of DERs

- Existing distribution planning tools mainly focus on steady state and quasi-steady state simulations
- There is a lack of models and simulation tools to study the transients and dynamics of distribution systems
- The DOE solar office awarded PNNL a $3M project titled "*Integrated Multi-Fidelity Modeling and Co-Simulation Platform for Distribution Systems Transient and Dynamic Analysis—DistribuDyn*" to investigate this issue

How to simulate the transient and dynamic behaviors of full-size distribution systems populated with many DERs?



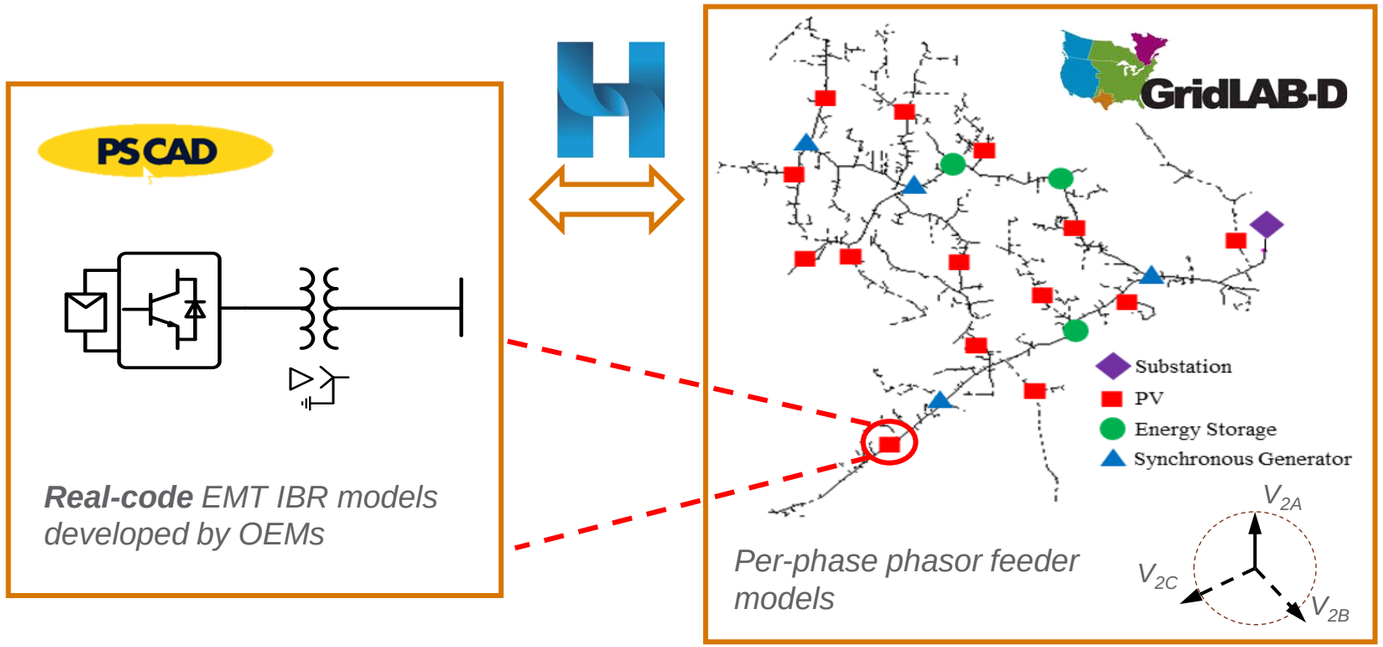
A modified IEEE 8500-Node Test Feeder with High Penetration of IBRs and VLs

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 38453. The views expressed herein do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

EMT and Per-phase Phasor Co-simulation Platform

- The project team achieved EMT and per-phase phasor co-simulation using PSCAD, GridLAB-D, and HELICS, which ensures model accuracy and improves simulation efficiency

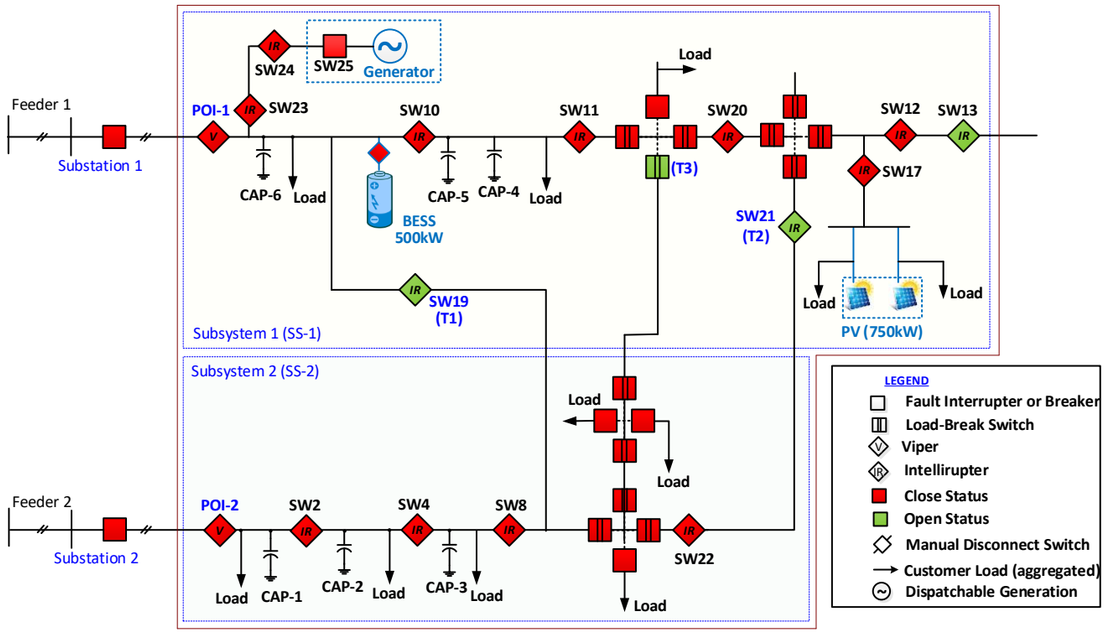
EMT/Per-phase Phasor Co-Simulation



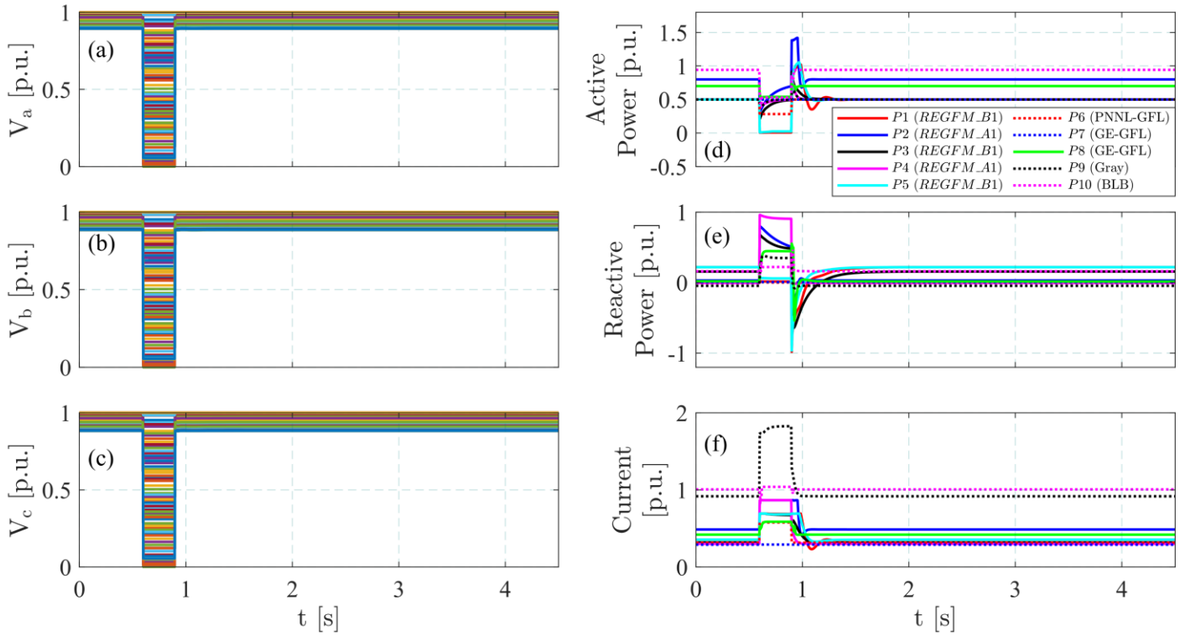
This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Solar Energy Technologies Office Award Number 38453. The views expressed herein do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

Industry Use of the Co-Simulation Platform

- The project team has collaborated with the utility partner ComEd on testing the DER models and simulation platform
- The ComEd team has evaluated how those DER models impact the transient and dynamic behaviors of their distribution feeder by performing various fault events using this simulation platform



One-line diagram for the studied ComEd Feeder
(***The feeder model has around 560 nodes***)



Simulation results of the ComEd feeder model with ten DERs

Summary

- Introduced the WECC standard library GFM models (REGFM_A1, REGFM_B1, and REGFM_C1) and use cases. These models have been integrated into utilities' everyday simulation tools
- Introduced the co-simulation platform developed by PNNL for simulating the transient and dynamic behaviors of distribution systems with a high penetration of DERs

Thoughts

- Many emerging power electronics component models are still lacking in commercial power system planning tools, and it is important to develop those models in those tools to accelerate the adoption of those technologies by utilities
- Investigate the distribution system protection coordination and fault location, isolation, and service restoration (FLISR) using the co-simulation platform

Pacific Northwest
NATIONAL LABORATORY

Thank you

Wei Du
Wei.du@pnnl.gov