Pacific Northwest NATIONAL LABORATORY

This project is funded by the DOE SETO Lab Call FY22-24

Project Period: 10/1/2021-9/30/2024

Integrated Multi-Fidelity Model and Co-Simulation Platform for Distribution System Transient and Dynamic Analysis

—DistribuDyn

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Project Team: PNNL, ORNL, GE Research, ComEd, Temple University

U.S. DEPARTMENT OF ENERGY BATTELLE

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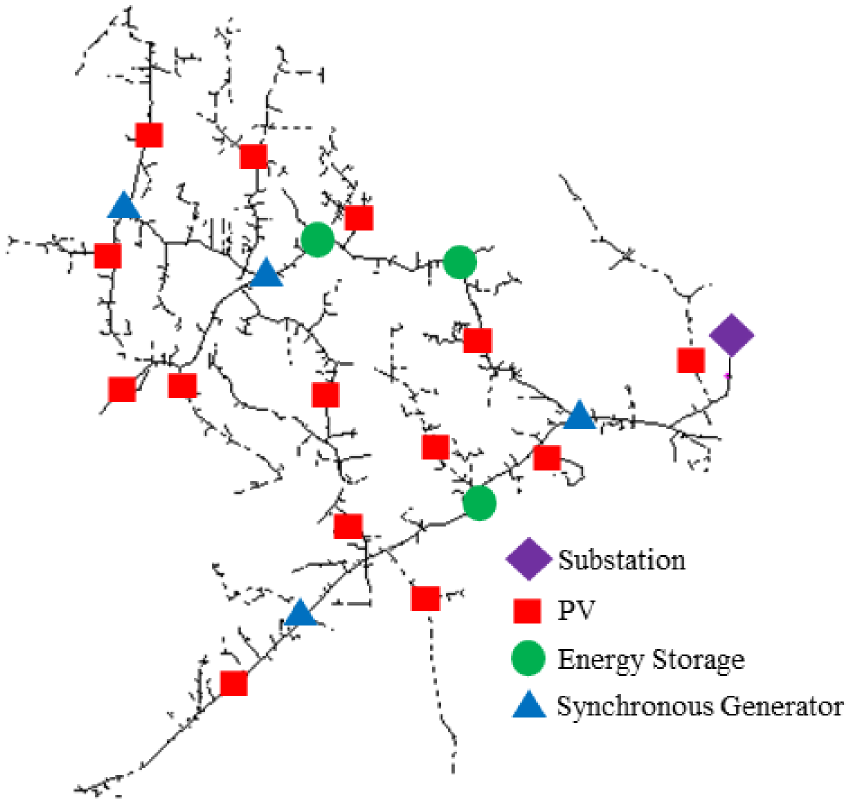
Outline

- Background & Motivation
- PNNL's Existing Work on Inverter Modeling for Microgrid Simulation
- *DistribuDyn* Project Overview
  - Technical Thrusts
  - End of Project Goals

Background & Motivation

- The power system is experiencing a major transition with increasing distributed, inverter-based resources (IBRs) and variable loads (VLs) connected at the distribution level.
- Today's power system simulation tools separate transmission (T) and distribution (D) systems, which is not suitable for future highly-interactive T&D power systems..
- Prior efforts have developed different models and tools to address this issue. However, there is still a lack of models and simulation platforms to accurately simulate the ***transients and dynamics of full-size distribution systems*** that feature high penetration of IBRs and VLs.
- The ***DistribuDyn*** project will develop multi-fidelity models of IBRs and VLs and an integrated co-simulation platform to accurately simulate the transient and dynamic behaviors of distribution systems and their interactions with transmission systems.

How should we simulate the transient and dynamic behaviors of full-size distribution systems populated with many IBRs and VLs, and their interactions with transmission systems?



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

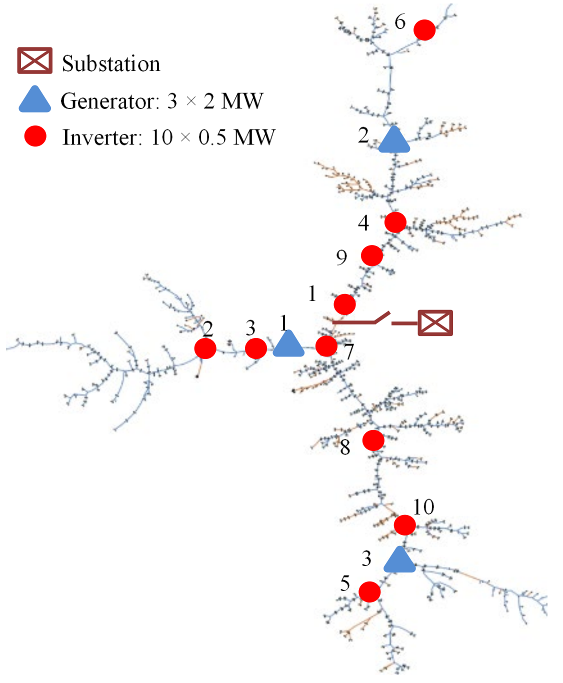
[1] Huang, Zhenyu, Hariharan Krishnaswami, Guohui Yuan, *et al*. "Ubiquitous Power Electronics in Future Power Systems: Recommendations to Fully Utilize Fast Control Capabilities." *IEEE Elec. Mag.*, vol. 8, no. 3, 2020.

PNNL's Existing Work on Inverter Modeling for Microgrid Simulation

The inverter modeling work for microgrid simulation is funded by the Microgrid R&D program, which is funded by the U.S. Department of Energy's (DOE) Office of Electricity (OE). The Microgrid R&D Program is managed by Mr. Dan Ton.

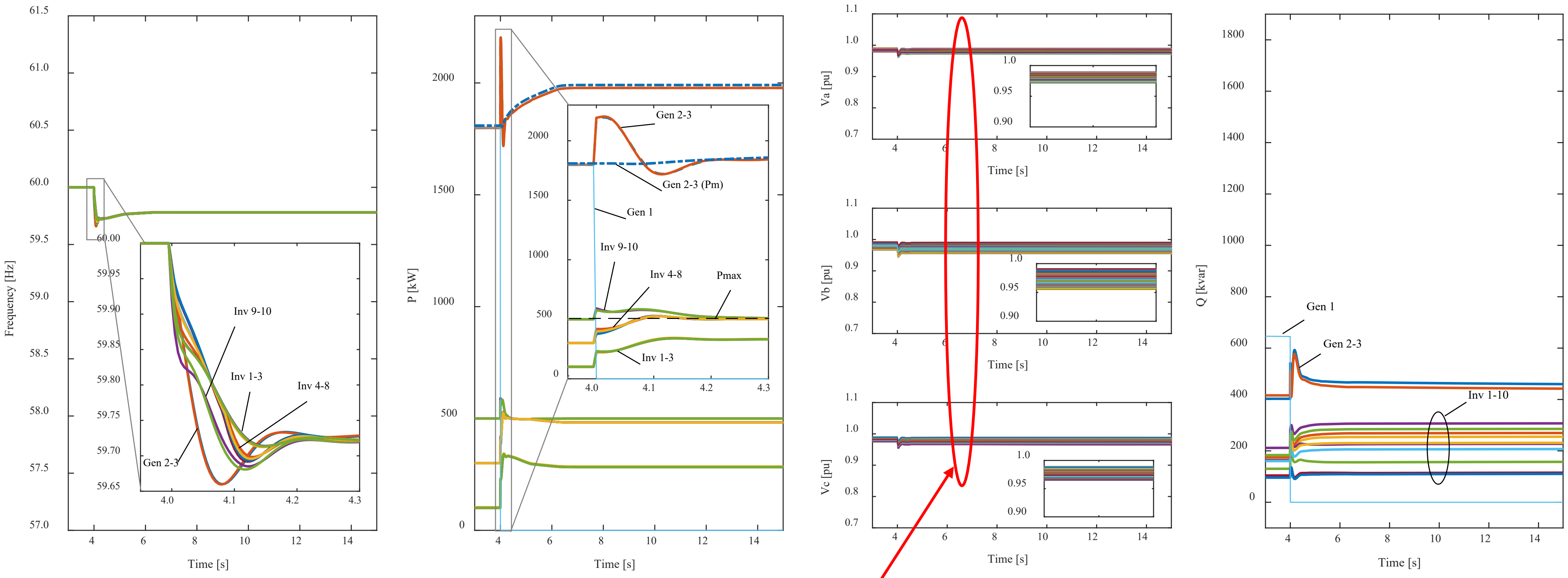
PNNL's Existing Work on Inverter Modeling for Microgrid Simulation

- PNNL has developed three-phase, phasor models of grid-forming and grid-following inverters, and integrate them in the open-source, distribution system simulation tool—GridLAB-D [1] for dynamic simulation of microgrids.
- The models has been simulated for a full-size, medium-voltage microgrid with 5,252 nodes [2].
- The simulation work of microgrids can support the study of the transients and dynamics of large-scale distribution systems with high penetration of IBRs and VLs.



An islanded 5,252-node microgrid

Case A: Three synchronous generators and ten grid-forming inverters in the microgrid



Per-phase phasor modeling

Event: Loss of one synchronous generator

Case A

Simulation Time	15 s
Time Step	5 ms
Computation Time	~13 mins

[1] http://gridlab-d.shoutwiki.com/wiki/Main_Page

[2] W. Du, F. K. Tuffner, K. P. Schneider, R. H. Lasseter, *et al.*, "Modeling of Grid-Forming and Grid-Following Inverters for Dynamic Simulation of Large-Scale Distribution Systems". IEEE Transactions on Power Delivery, 2020.

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Project Overview

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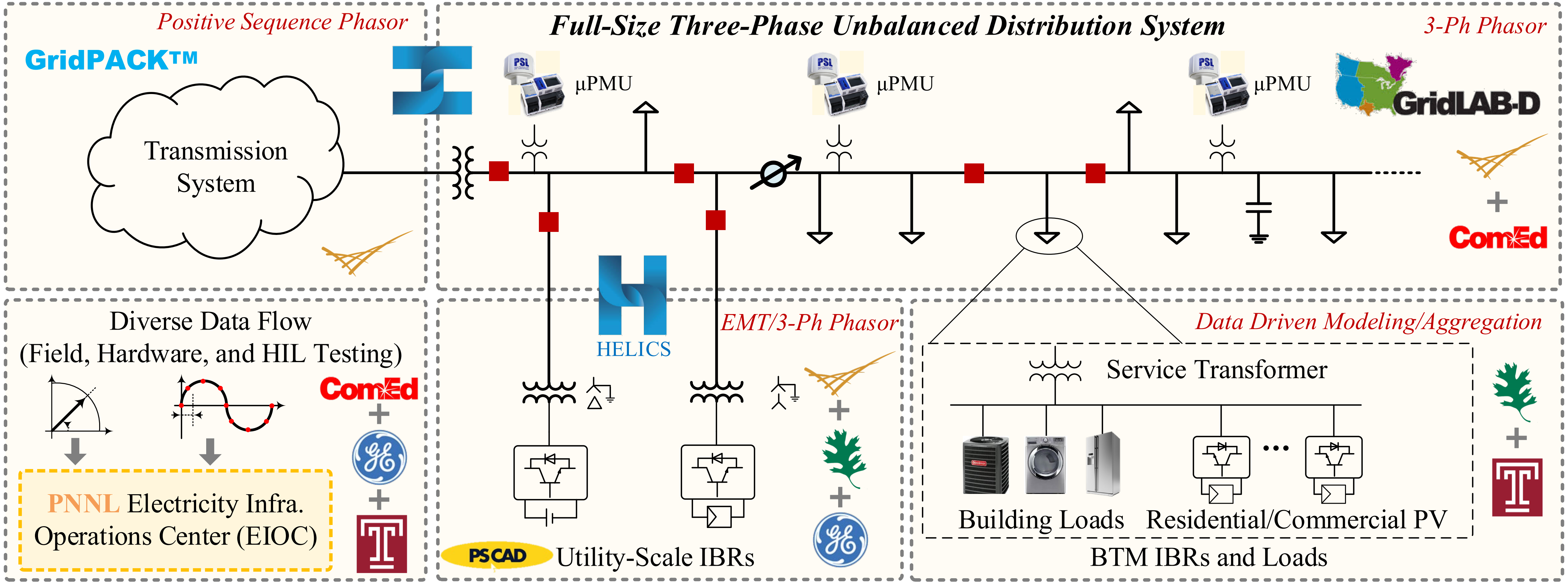
- Develop multi-fidelity IBR and VL models and an integrated co-simulation platform to accurately simulate the ***transients and dynamics*** of distribution systems and their interactions with transmission systems
  - Utilize ***white-, black-, and gray-box*** modeling approaches to model utility-scale and BTM IBRs and VLs
  - Leverage and expand open-source tools (i.e.,***GridLAB-D***, ***HELICS***, and ***GridPACK***) for various types of co-simulation
  - Validate and calibrate the models based on ***μPMU*** and ***point-on-wave*** data from ***real-world feeders***

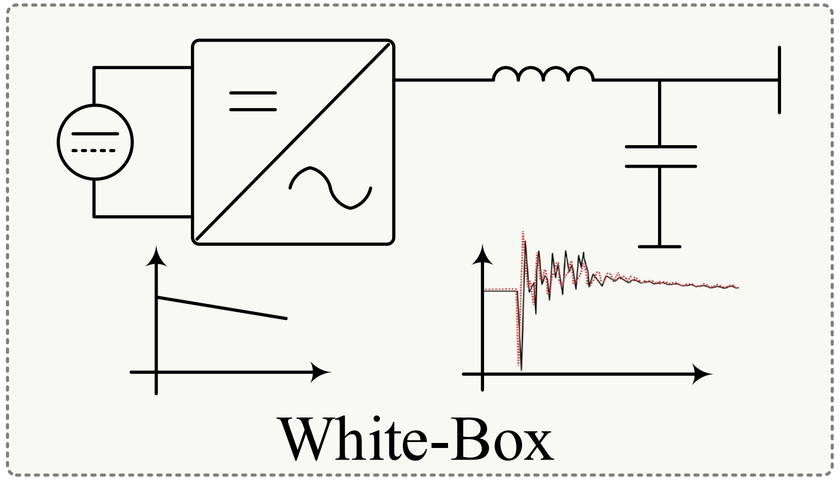


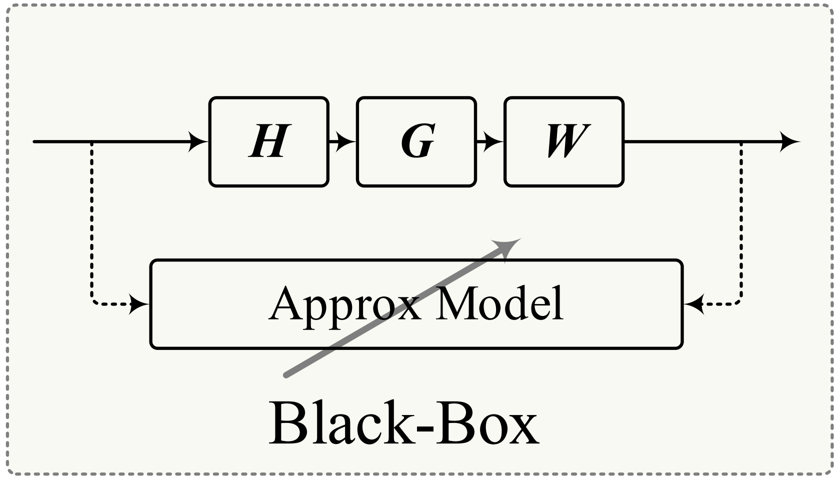
Overview of technical solutions and team composition

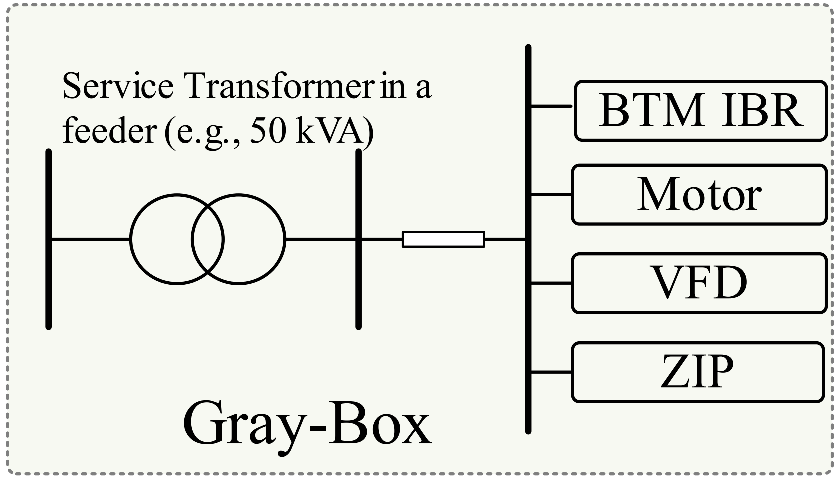
Project Period: 10/1/2021-9/30/2024

Thrusts 1: Physics-Based and Data-Driven Modeling of IBRs and VLs

- ***White-Box Modeling***
  - High-resolution EMT and phasor models for utility-scale IBRs (large distribution-connected IBRs)
  - Various control strategies (e.g., grid-forming and grid-following controls) and inverter built-in protection
  - Focus on large-signal transient behaviors (e.g., various fault responses of IBRs)
- ***Black-Box Modeling***
  - Data driven approach to model vendor-specific IBRs ideally only using the nameplate information
  - Nonlinear autoregressive exogeneous (NARX) and/or Hammerstein-Wiener (HW) approaches to model IBR nonlinear transients
- ***Gray-Box Modeling***
  - Aggregate the residential and commercial BTM IBRs and VLs behind a service transformer
  - Single-/three-phase BTM IBRs and representative building loads (e.g., direct-connected and inverter-driven motors with various mechanical torque characteristics and protection)



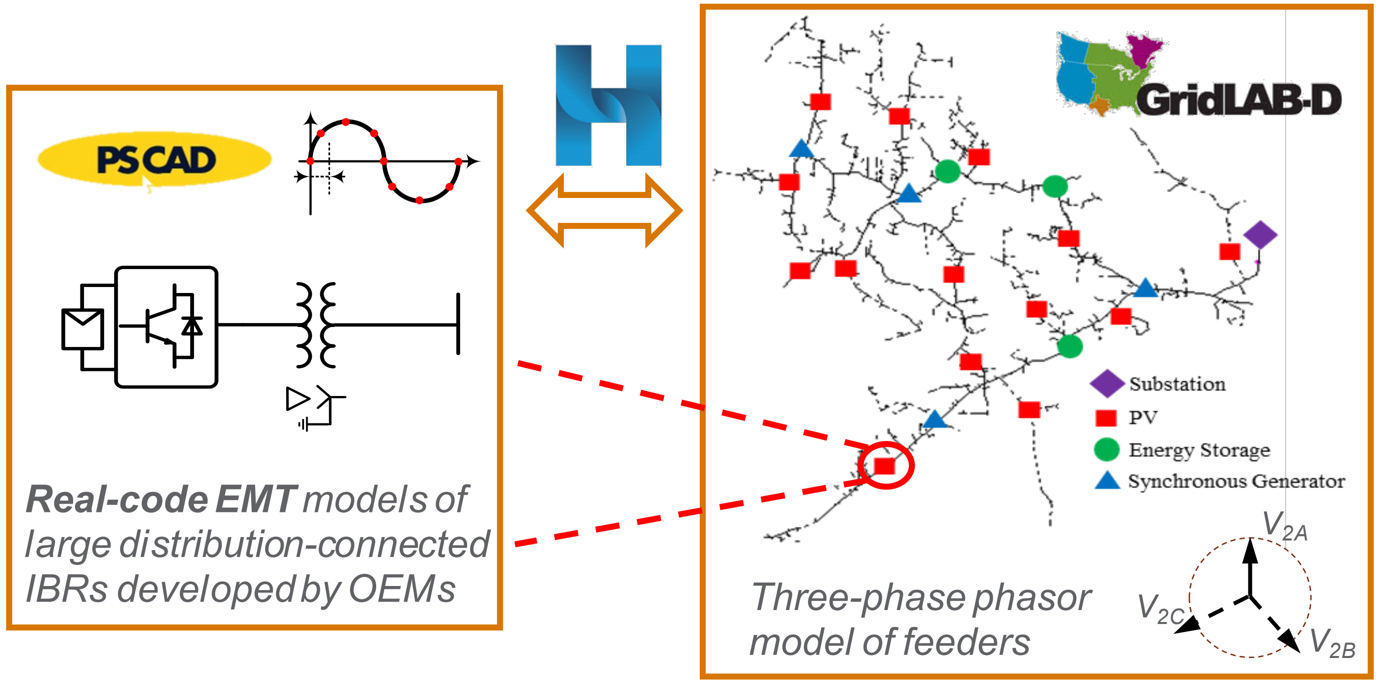




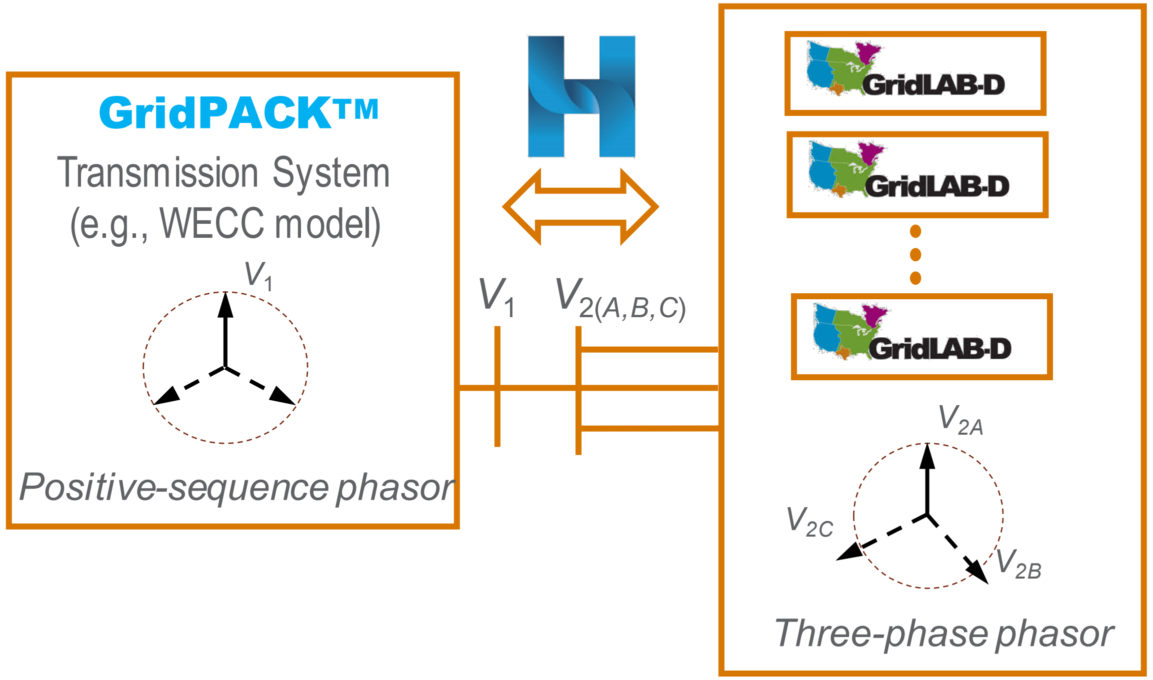
Thrusts 2: Integrated Co-Simulation Platform Development

- ***EMT and Three-Phase Phasor Co-Simulation***
  - Expand Hierarchical Engine for Large-scale Infrastructure Co-Simulation (HELICS[1]) platform to interconnect PSCAD and GridLAB-D to realize EMT & phasor co-simulation for distribution systems
  - Allow ***real-code*** PSCAD EMT models of IBRs to be directly connected to utilities' full-size feeder models
- ***Large-Scale T&D Co-Simulation***
  - Expand HELICS to interconnect GridPACK and GridLAB-D to realize large-scale T&D co-simulation
  - Leverage ***parallel computing*** to address the scalability issue

EMT and three-phase phasor co-simulation to study the transients and dynamics of distribution systems



Large-Scale T&D Co-Simulation to study the T&D interaction



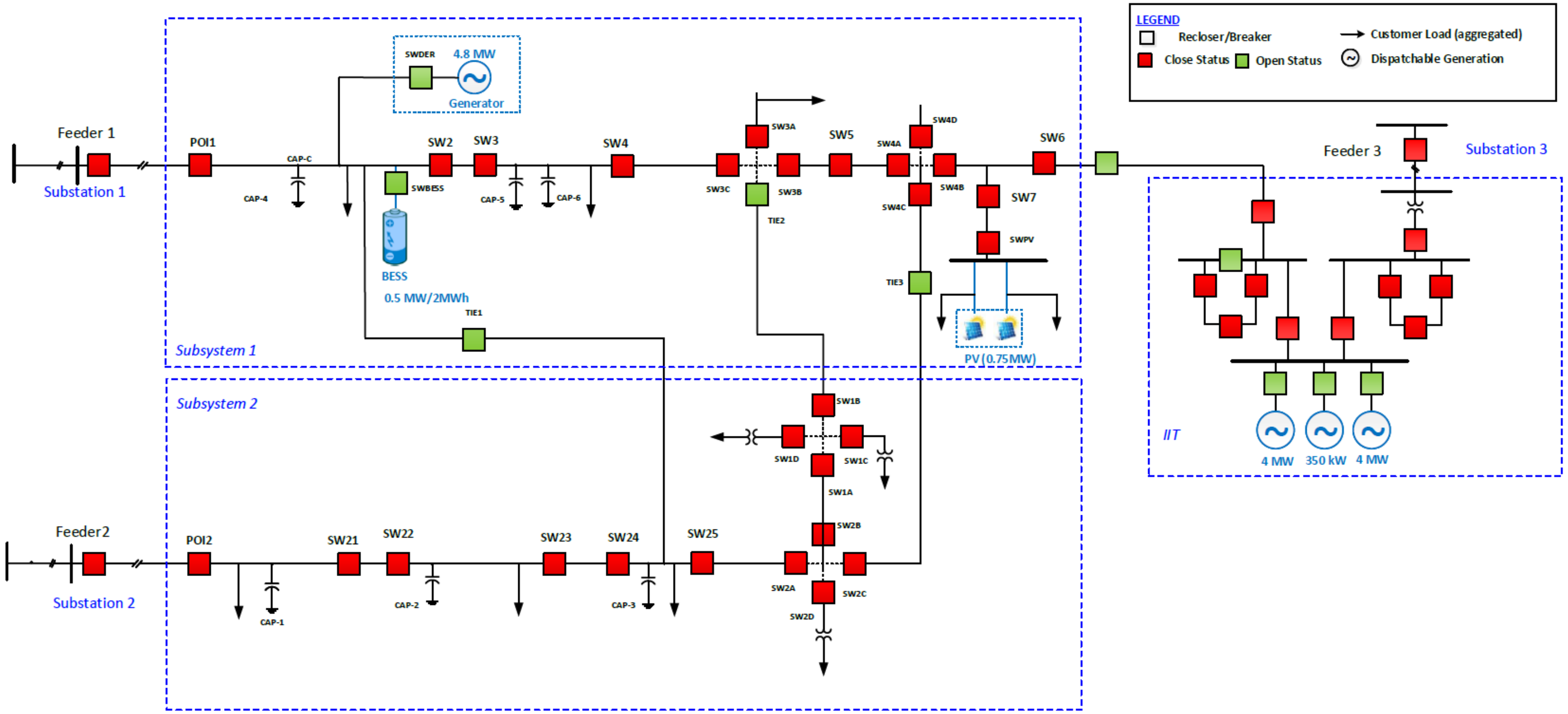
[1] https://helics.org/

Thrusts 3: Model Validation and Calibration

- ***Data Collection, Model Validation and Calibration***
  - High-resolution ***μPMU*** and ***point-on-wave*** data from the ComEd feeder
  - Extensive laboratory ***HIL*** and ***hardware*** testing of utility-scale/BTM IBRs, and direct-connect and inverter-driven motors
  - IBR models, VL models, and feeder models will be validated against field data

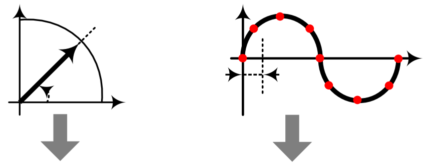
Thrusts 4: Contingency Analysis Using the Developed Co-Simulation Platform

- ***Contingency Analysis of Distribution Systems***
  - Switching, balanced and unbalanced faults, reclosing, etc.
- ***Contingency Analysis of T&D Systems***
  - Delayed-clearing faults, loss of generation units, etc.



One-Line Diagram of the Studied ComEd Feeders

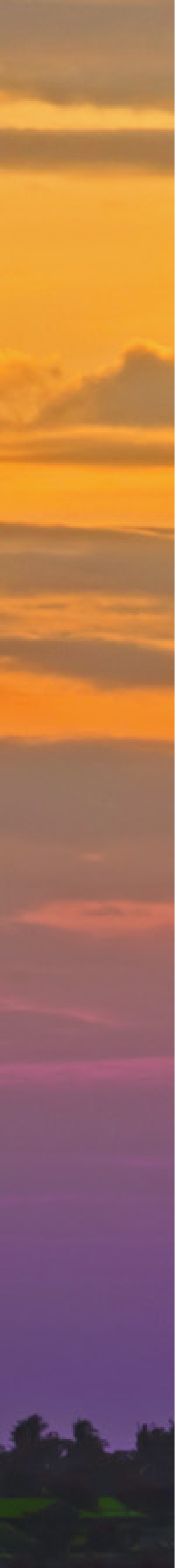
Diverse Data Flow
(Field, Hardware, and HIL Testing)



PNNL Electricity Infra. Operations Center (EIOC)

End of Project Goals

Model Accuracy	***Individual Component***: For the developed white-, black-, and gray-box models, the normalized root mean squared error (NRMSE) of individual IBR/VL output between simulation and field measurements/hardware testing should be less than 2% with a confidence level higher than 95%.
	Distribution Feeder: For the ComEd feeder model, the voltage and frequency NRMSE of the nodes equipped with μPMUs between simulation and field measurements should be less than 5% with a confidence level higher than 90%.
Scalability	***Distribution System Simulation***: Achieve transient and dynamic simulation of a modified IEEE 8500-node test feeder with above 75% penetration of IBRs on a personal computer. The feeder should have at least 100 phasor IBR models (residential/commercial) and 5 EMT IBR models (utility-scale).
	T&D Co-Simulation: Achieve large-scale T&D co-simulation with the full-size WECC system and 100 detailed distribution feeders on a supercomputer leveraging parallel computing.



Thank you

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