



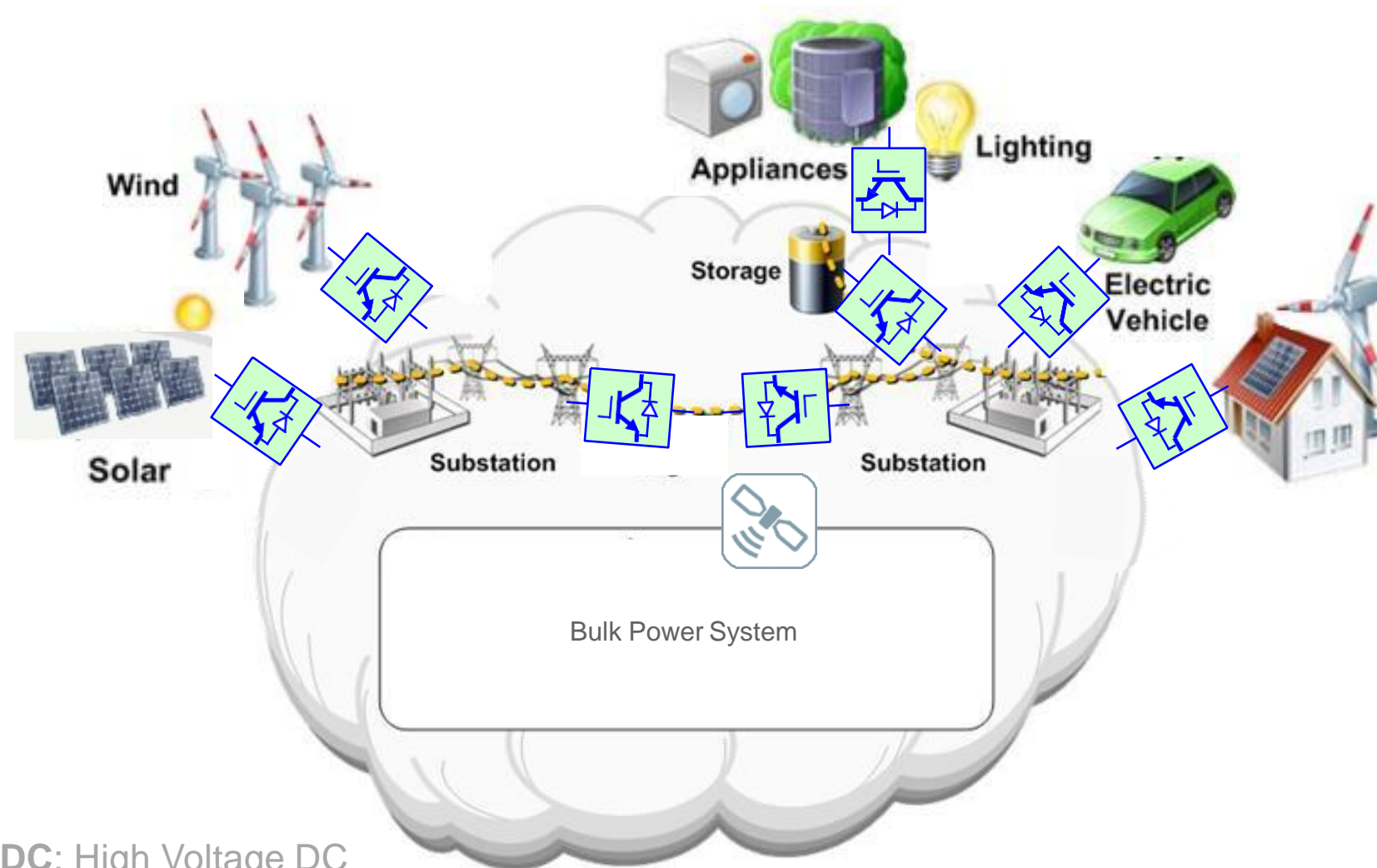
PE@PNNL: Power Electronics for a Better Future Grid

Wei Du
Pacific Northwest National Laboratory



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

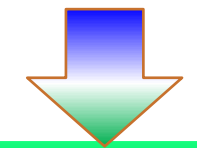
Ubiquitous power electronics at all levels



HVDC: National transmission upgrades
MVDC: Offshore wind and regional transmission
LF-HVac: Offshore wind integration and reconductoring
LVDC: Inverters for renewables, EVs, storage, ...



Challenge:
 low inertia →
 new dynamics
 → new control

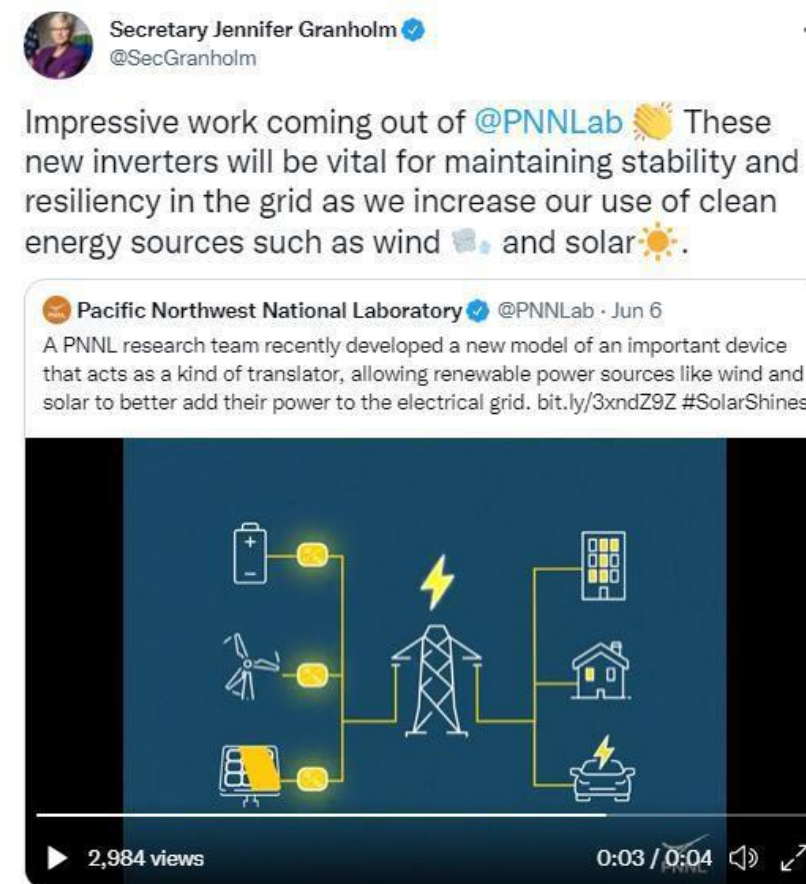
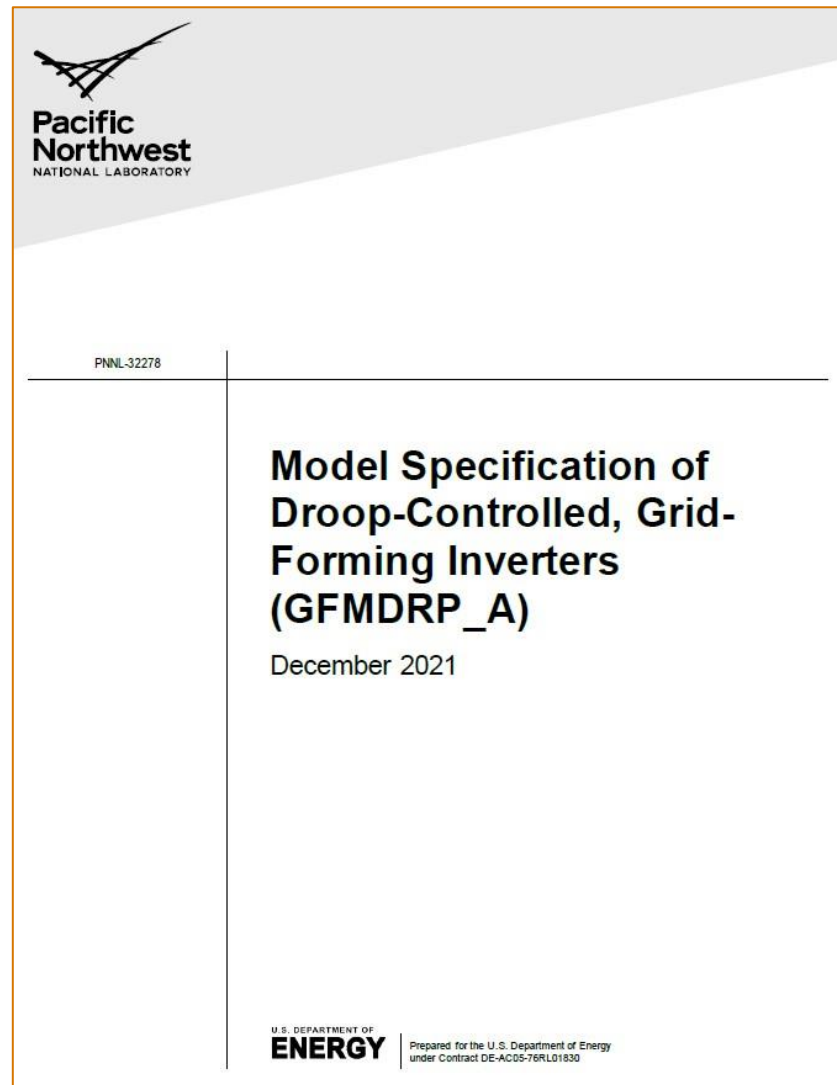


Opportunity:
 higher
 controllability
 and flexibility

HVDC: High Voltage DC
 MVDC: Medium Voltage DC
 LF-HVac: Low-Frequency High Voltage AC
 LVDC: Low Voltage DC

WECC adopted the grid-forming inverter model (REGFM_A1) led by PNNL

- Grid-forming inverters are vital for renewables and energy storage to maintain the stability of power grids
- PNNL-developed model specification of [droop-controlled, grid-forming inverters](#) was approved by WECC [1]
- This is the first grid-forming inverter model spec adopted by WECC
- *The beta version of REGFM_A1 model has been included in the model libraries of PSS/E, PSLF, PowerWorld, and TSAT*

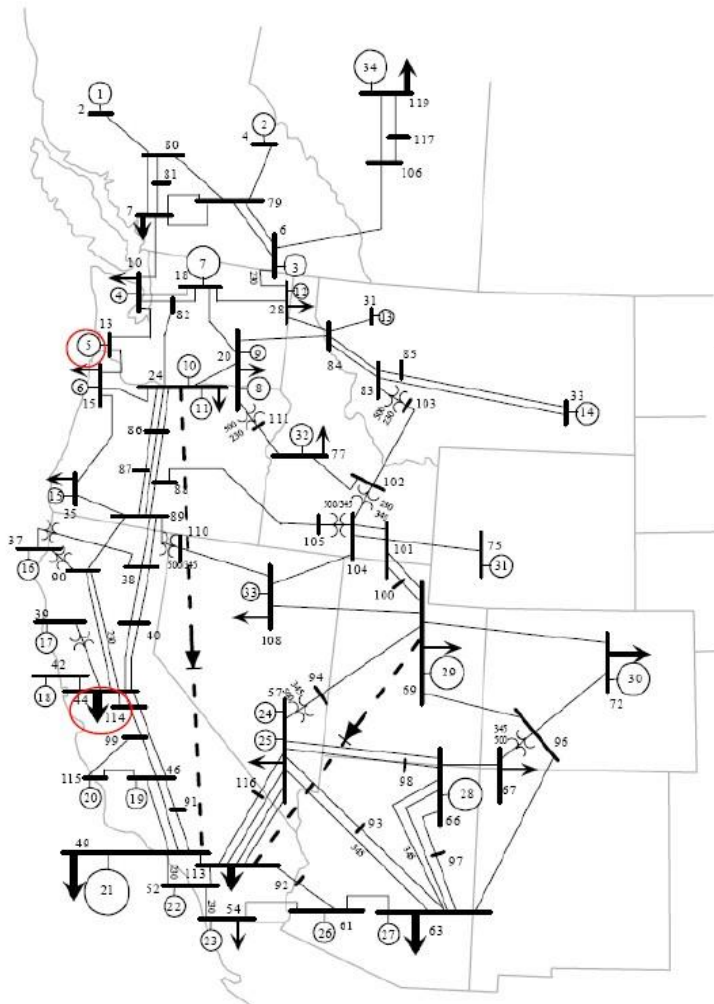


Twittered by Secretary of Energy Jennifer M. Granholm

Integrated T&D Co-Simulation Platform

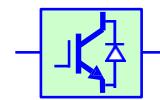
- Developed a T&D co-simulation platform leveraging DOE invested open-source tools GridPACK, HELICS, and GridLAB-D
- System size: **10,000+ IBRs**, and **160,000+ nodes**
- The platform can be used to investigate the impact of grid-following (GFL) and grid-forming (GFM) IBRs on the system dynamic stability at any penetration levels (up to 100%)

GridPACK™

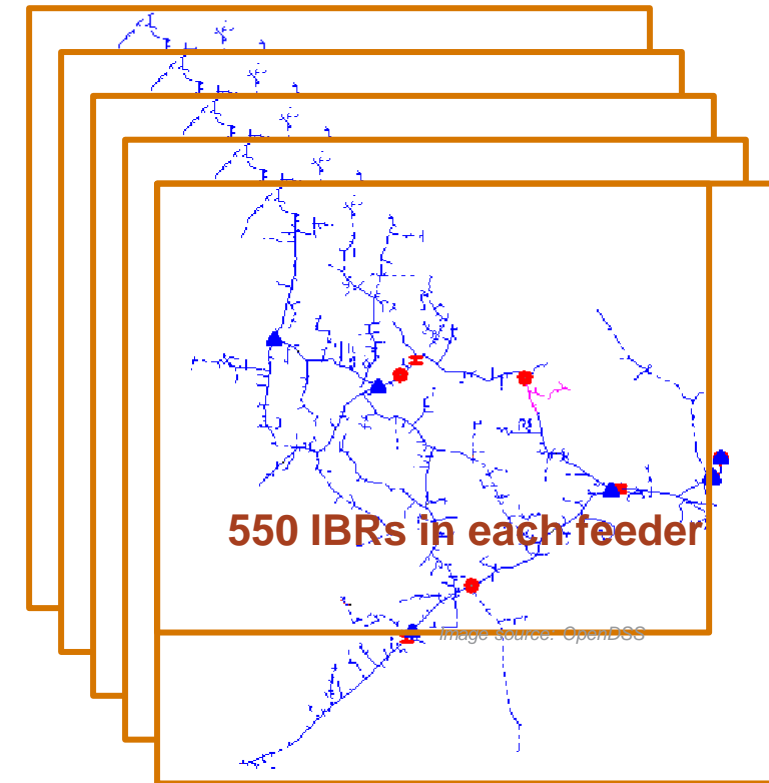


MinniWECC system

All 19 load buses of the MinniWECC system are replaced by detailed feeder models



10,000+ IBRs



Modified IEEE 8500-Node TestFeeder

Demonstration of Grid Services by a 380 MW Wind, Solar, and Battery Storage Combined Power Plant

- Wheatridge Renewable Energy Facility is **North America's first energy center to combine wind, solar, and battery storage in one location**, with 300 MW of wind, 50 MW of solar, and 30 MW of energy storage systems
- This will be **the first time that grid forming IBRs, including both wind and battery storage, are connected to the US bulk power systems**, and demonstrated at the same site for grid services



380MW Wheatridge wind, solar and battery storage power plant

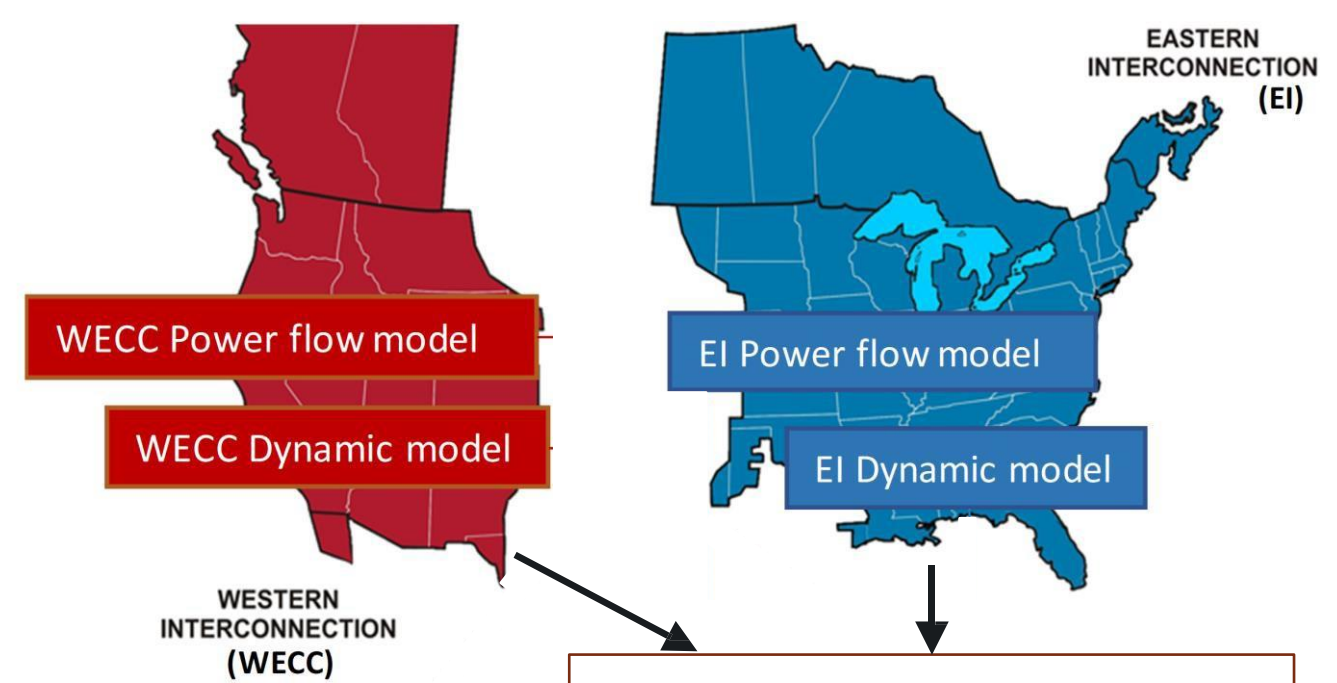
One line diagram



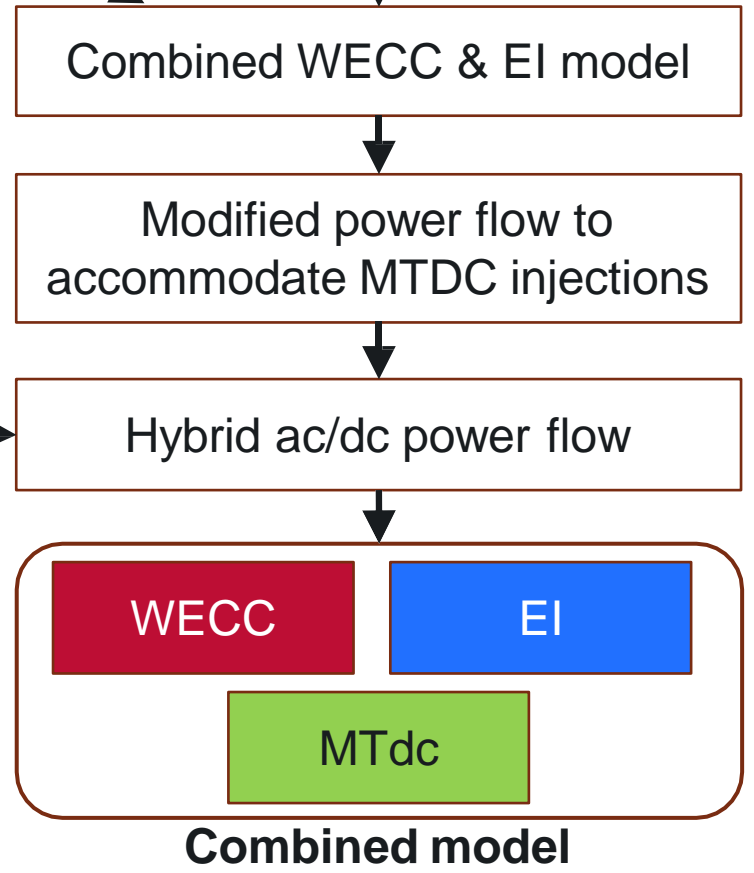
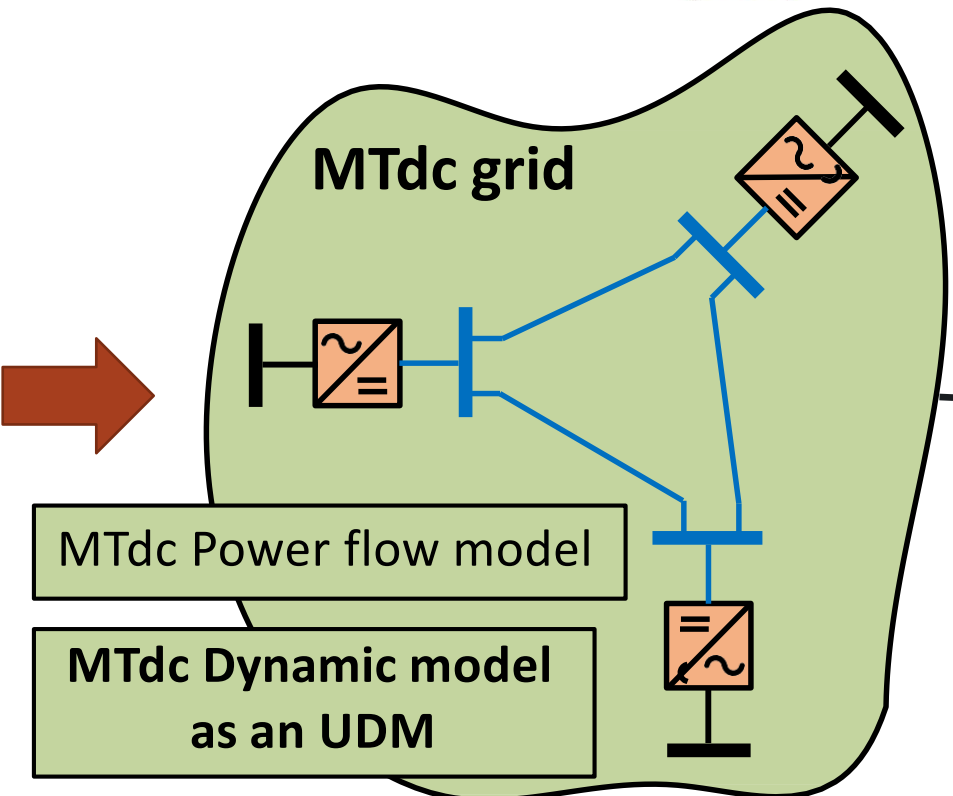
Interconnection-level TS Dynamics for HVDC Grids



- Full steady-state and TS model of an MTdc grid at interconnection level
 - Able to model different MTdc grid topologies (monopolar/bipolar) and number of terminals
 - Flexible to develop and study different converter controls (grid forming, grid following), and grid supporting functions (voltage and frequency support)



Positive-sequence or EMT models of MTdc systems



Real-Time Simulation/HIL Testing Capability at PNNL

➤ Physical Process Emulation

- 3 Opal-RT simulators with I/O capabilities

➤ SCADA Capability and Automation

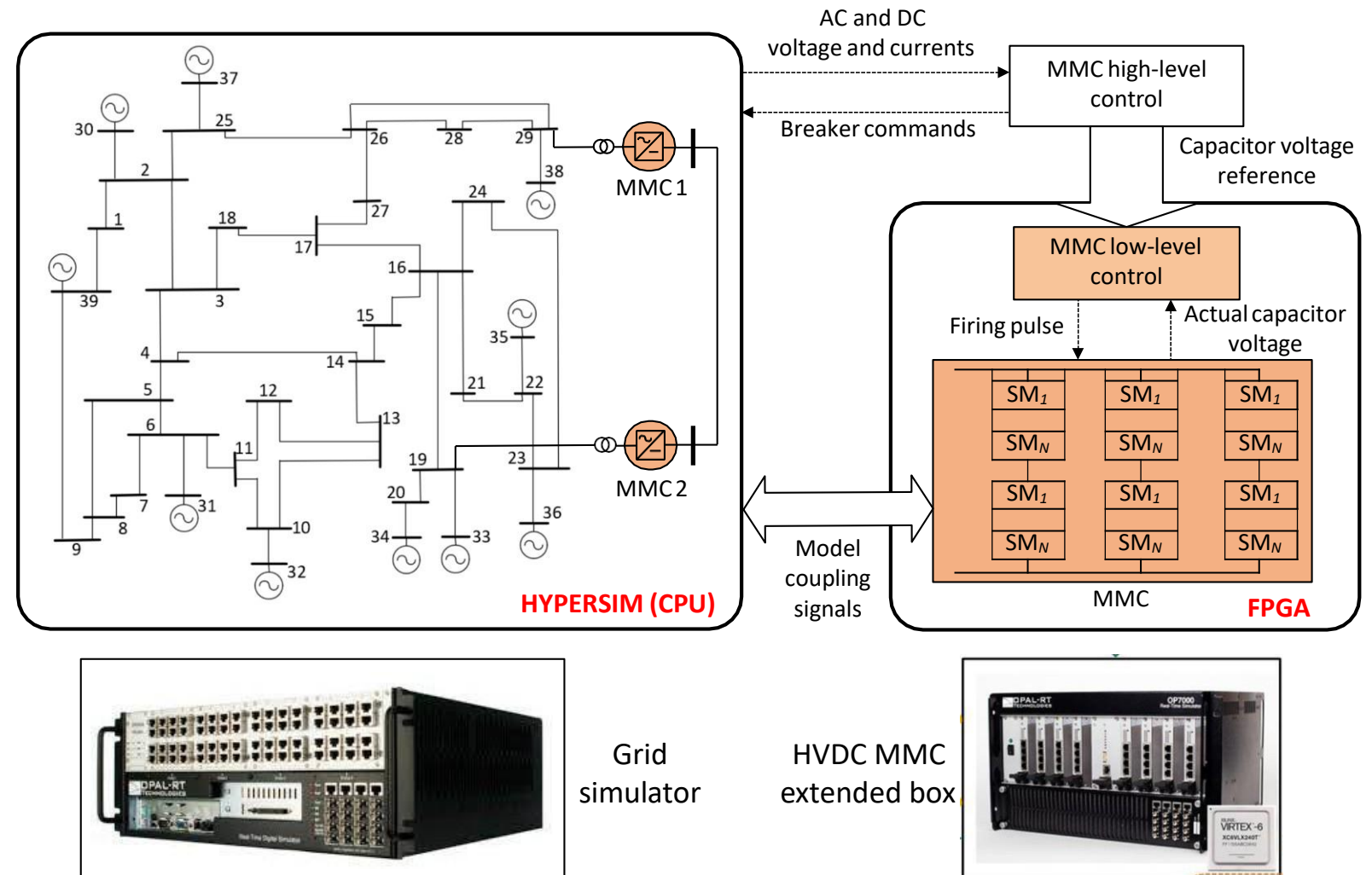
- SEL RTAC, OPC Server, and support for Modbus, DNP3, and many other protocols

➤ Multi-vendor power devices (RTU, relays, meters, microgrid controllers, PMUs)

- 11 SEL, 7 ABB, 5 GE, 4 Siemens, and 3 others

➤ Newly purchased HVDC MMC emulators

- Currently allow simulation of a two-terminal HVDC system with each value having 256 units
- Will further expand for a multi-terminal HVDC system in the next year



Grid simulator



HVDC MMC extended box

Real-Time Simulation Platform for MTDC

We need a national scale hybrid platform to study power electronics at all levels

This work is supported by the Energy System Co-Design with Multiple Objectives and Power Electronics (E-COMP) Initiative, the Resilience Through Data-Driven, Intelligently Designed Control (RD2C) Initiative, and other LDRD programs at PNNL

Thank you

