DER Impact Studies

Co-simulation of Transmission, Distribution, and DERs

Jason Fuller and Henry Huang

Pacific Northwest National Laboratory

U.S. DEPARTMENT OF ENERGY BATTELLE

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

Growing distributed participation is changing the operational landscape

- Distributed generation including distributed solar rapidly growing.
- Loads (buildings) are becoming actively responsive to system conditions.
- Electric vehicles creating mobile power consumptions.

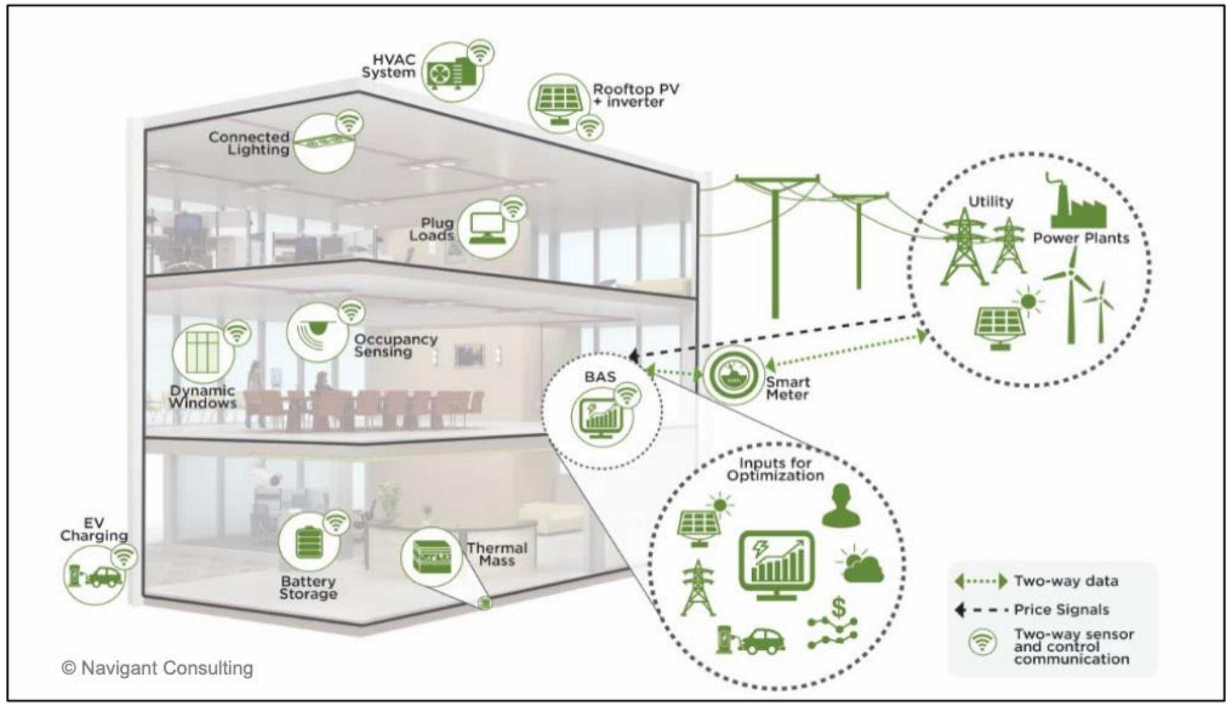


Image Source: EERE BTO GEB Overview, 2019

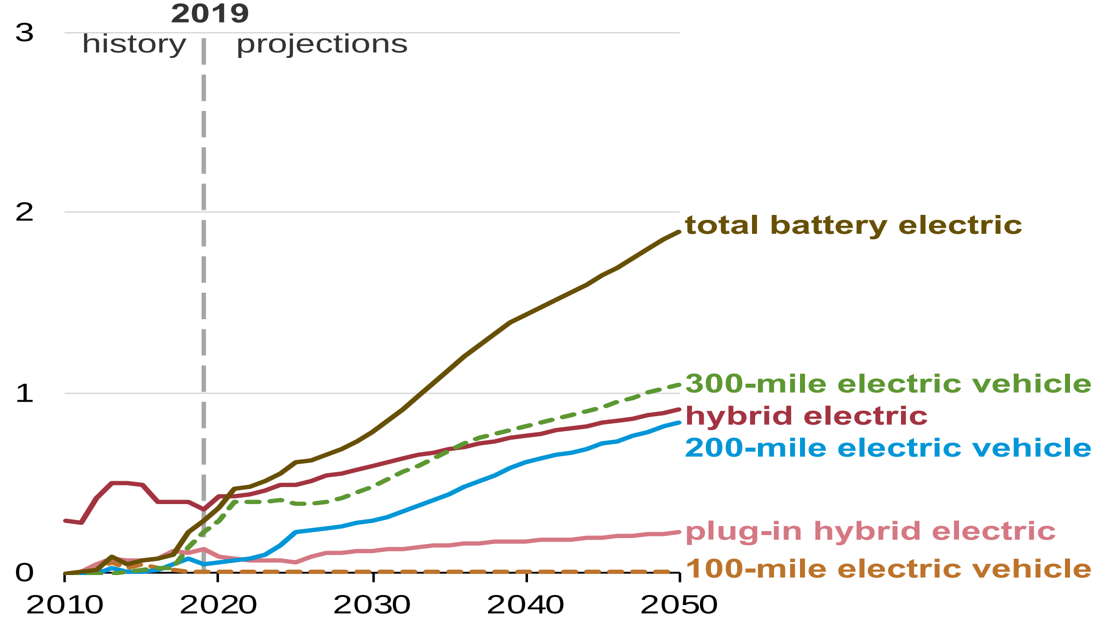


Image Credit: EIA AEO 2020

Some big questions requiring multi-physics, multi-scale, multi-fidelity analytics…

- How much cyber vulnerability (cyber failures and threats) would be added by the increasing penetration of smart meters (e.g. firmware risks)? (T + D + Comms)
- Can Distributed Energy Resources (DERs) be used for blackstart and emergency response and thus improving grid resiliency? (T + D + Comms)
- How would hurricane damages propagate through the power grid? (T + D)
- Would growing inverter-based generation destabilize the grid due to reduced inertia and what can be done? (fast + slow dynamics)
- How to ensure fuel security for electricity generation? (grid + gas, etc.)
- How to optimize disaster logistics and recovery? (grid + transportation)
- …

Analyzing Large and Complex Systems through Co-Simulation

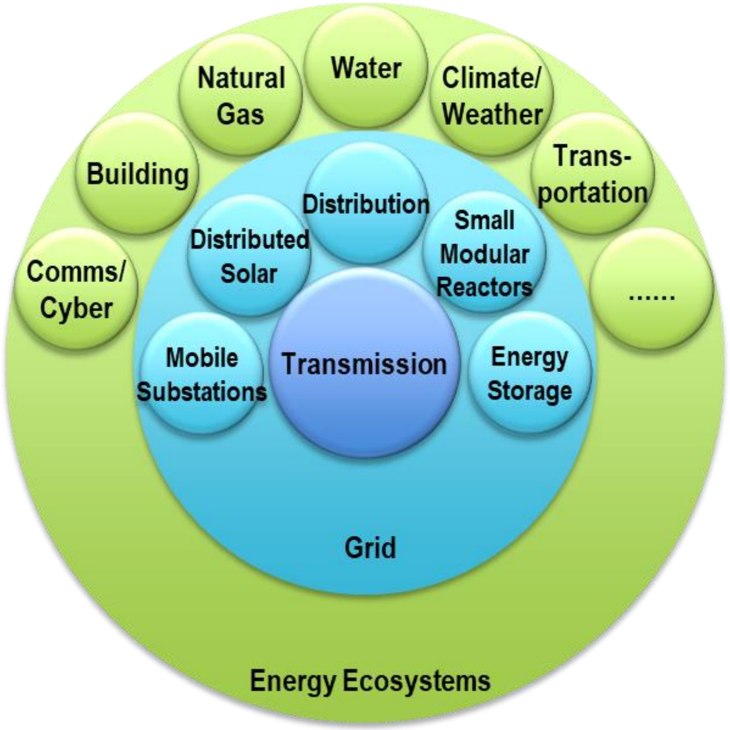
- Co-simulation is a method for unifying multiple models in a coordinated fashion.
  - Models may or may not cover similar domains
  - Models may or may not have a similar concept of time
  - Models may or may not be written in the same language
  - Simulators using models may or may not run on the same computer or operating system, or be in the same network

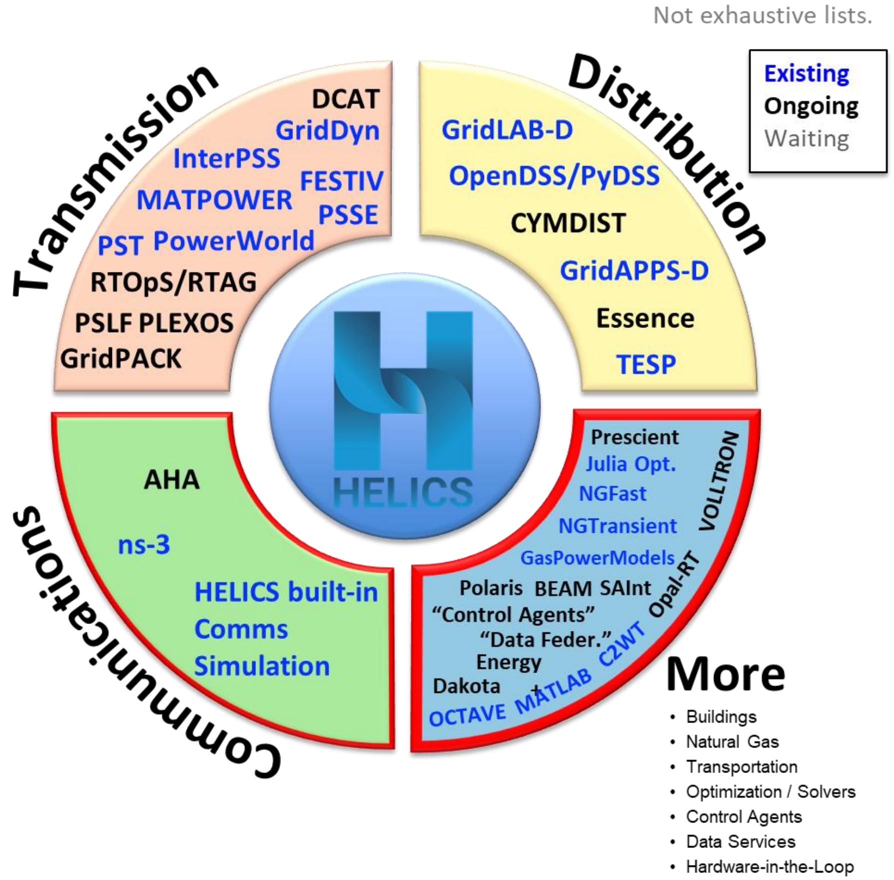
- Co-simulation allows models that have interactions with each other to express those interactions and influence each other's behavior.

The Value of Co-Simulation

Interdependence across Multiple Domains

- There is increasing interdependence between critical energy infrastructures – Natural Gas and Grid, Telecommunications and Grid, Distribution and Transmission, Buildings/DERs and Grid, EVs and Grid, etc.
- Comprehensive system analysis is necessary to understand the relationships, dependencies, constraints, and joint evolution of these interconnected systems.
- Co-simulation is only *one* approach that leverages existing tools, data, and models.



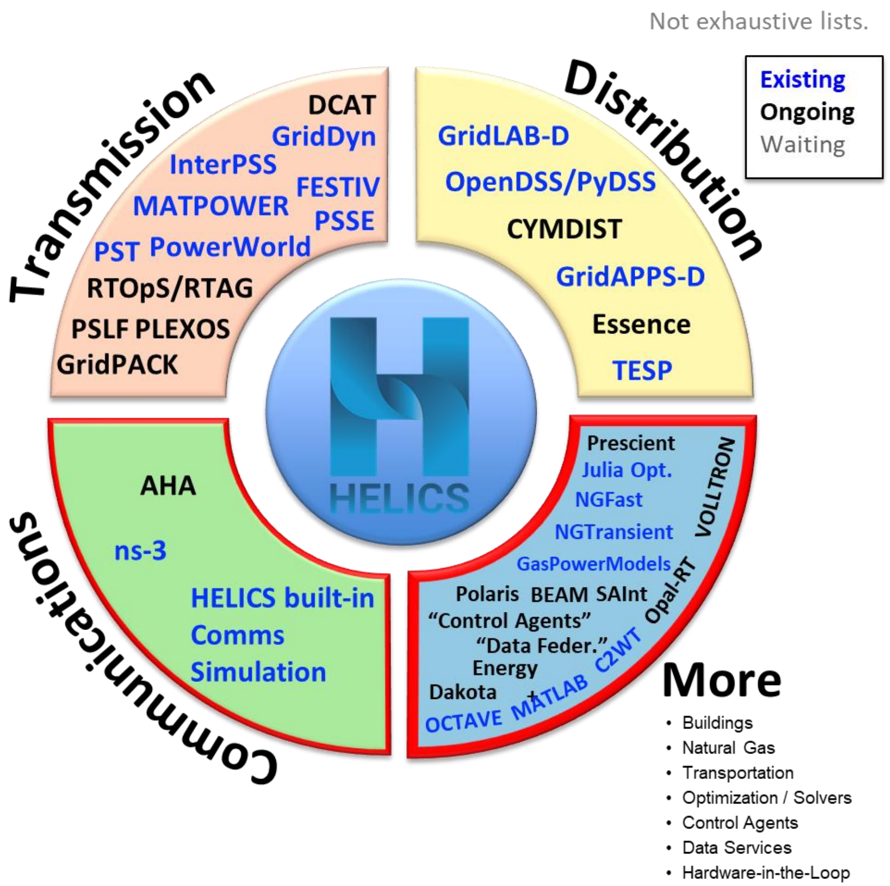


HELICS interfaces to popular domain simulators, ready for user applications

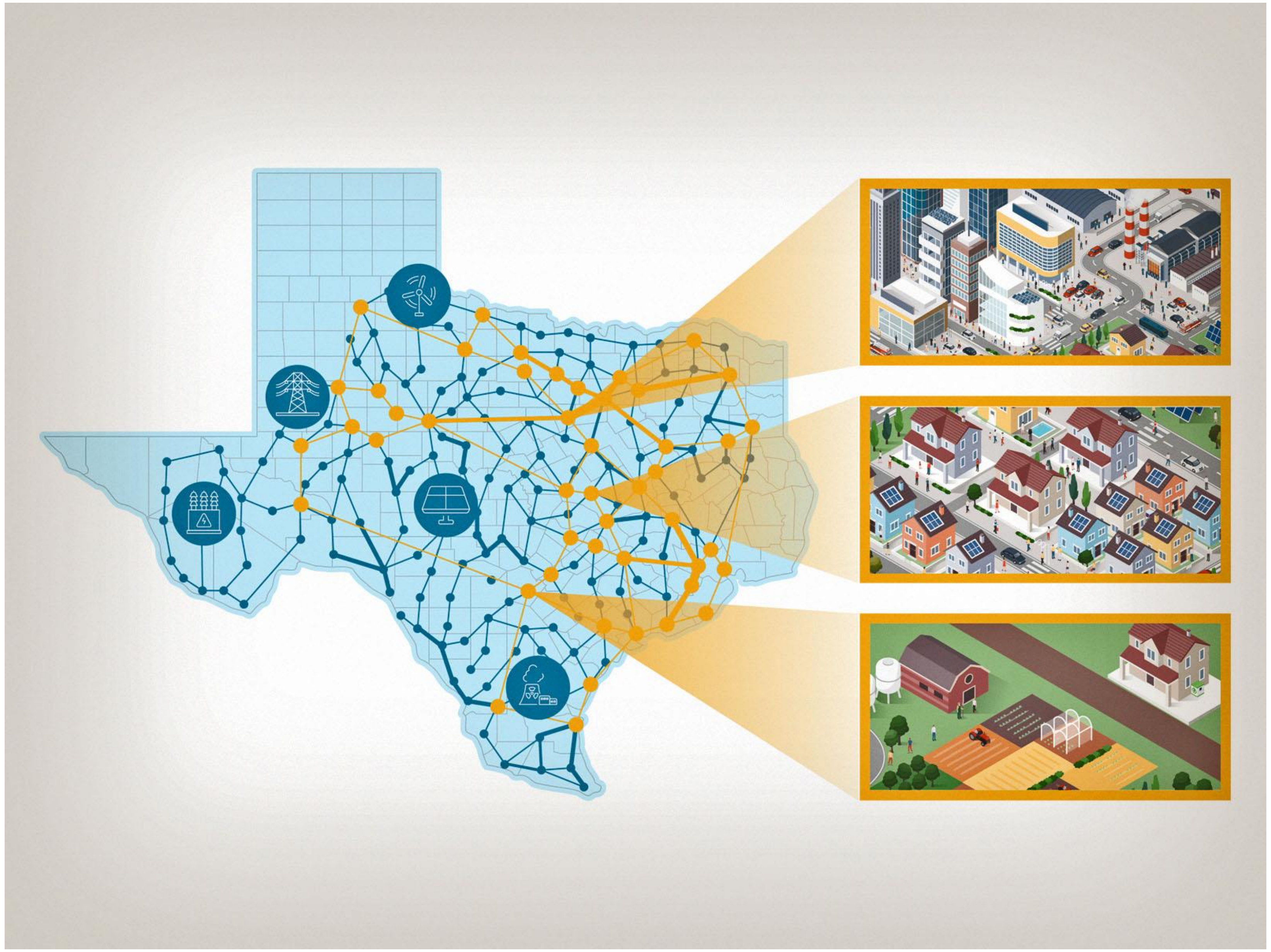
- Enable large-scale interdependency all-hazards studies: scale 2 to 100,000+ domain simulators
- Diverse simulation types:
  - Continuous, discrete, time series
  - Steady-state, dynamic, transient
  - Other energy systems
- Support multiple platforms: HPC, cloud, workstations, laptops (Win, Linux, Mac)
- Support standards: HLA, FMI, …
- Core for DOE NAERM (North American Energy Resilience Model)

www.helics.org
Developed by the DOE Grid Modernization Laboratory Consortium.

(PNNL, LLNL, NREL, ANL, ORNL, SNL, INL)



Example T+D Projects

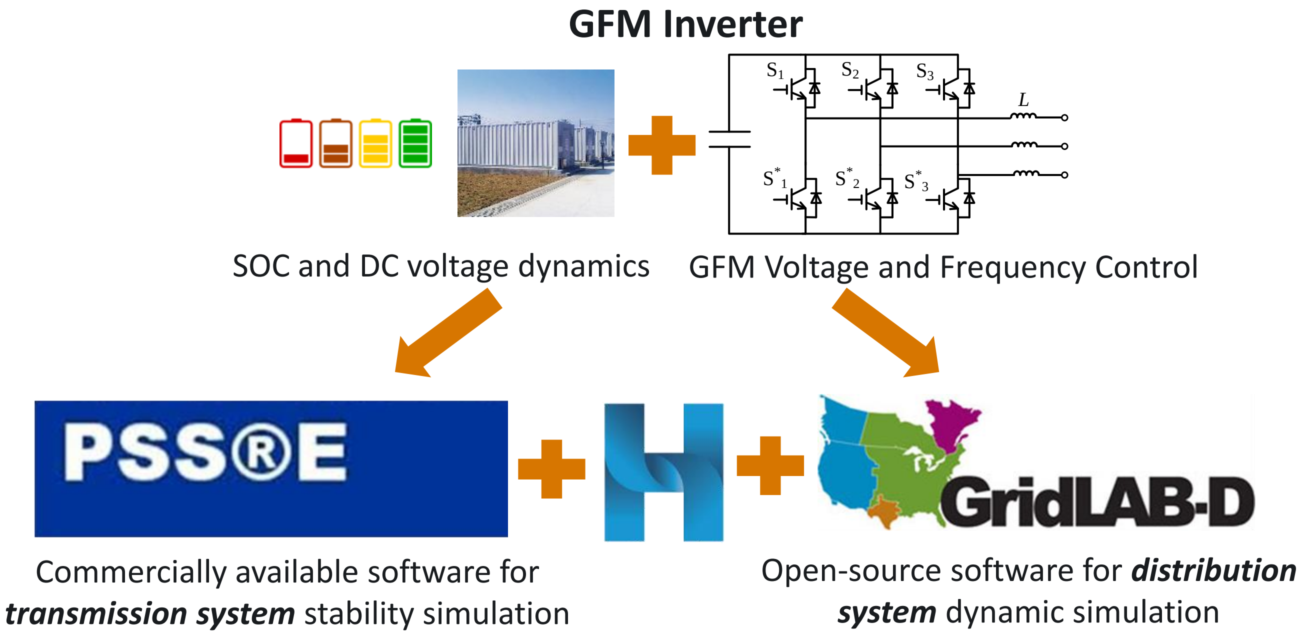


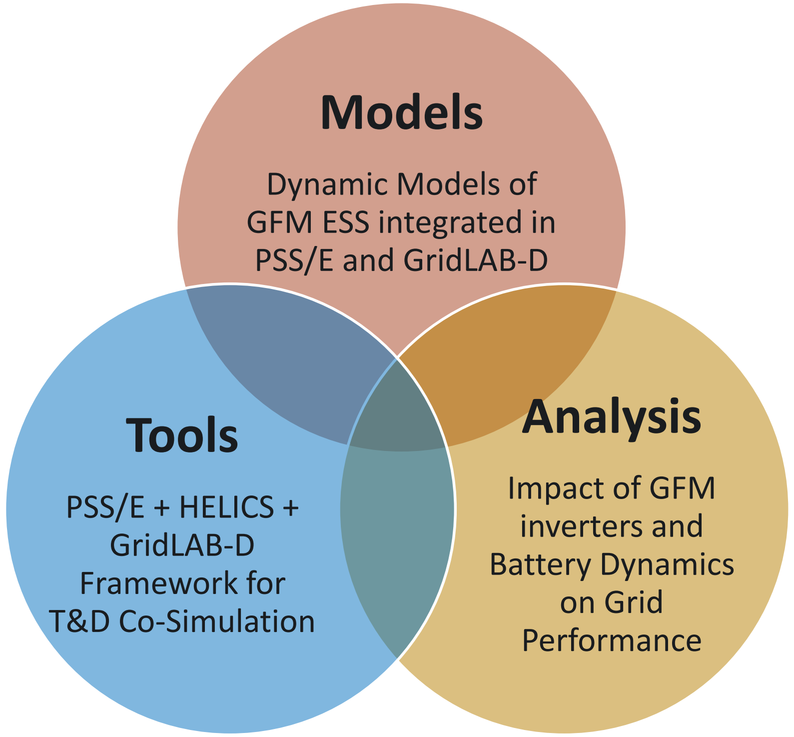
Grid-Forming Energy Storage Systems for Improved Stability of Low-Inertia Bulk Power Grids through T&D Integration

Wei Du (PI), Yuan Liu (Co-PI) , Alok Kumar Bharati, Frank Tuffner, Ankit Singhal, Bishnu P Bhattarai

Objective: Investigate the ***dynamic stability*** of bulk power system with high penetration of inverter-based distributed energy resources (DERs)
Simulation: T&D co-simulation achieved through PSSE/HELICS/GridLAB-D co-simulation.
Models: Grid-forming (GFM) and Grid-following (GFI) inverter models developed in GridLAB-D.

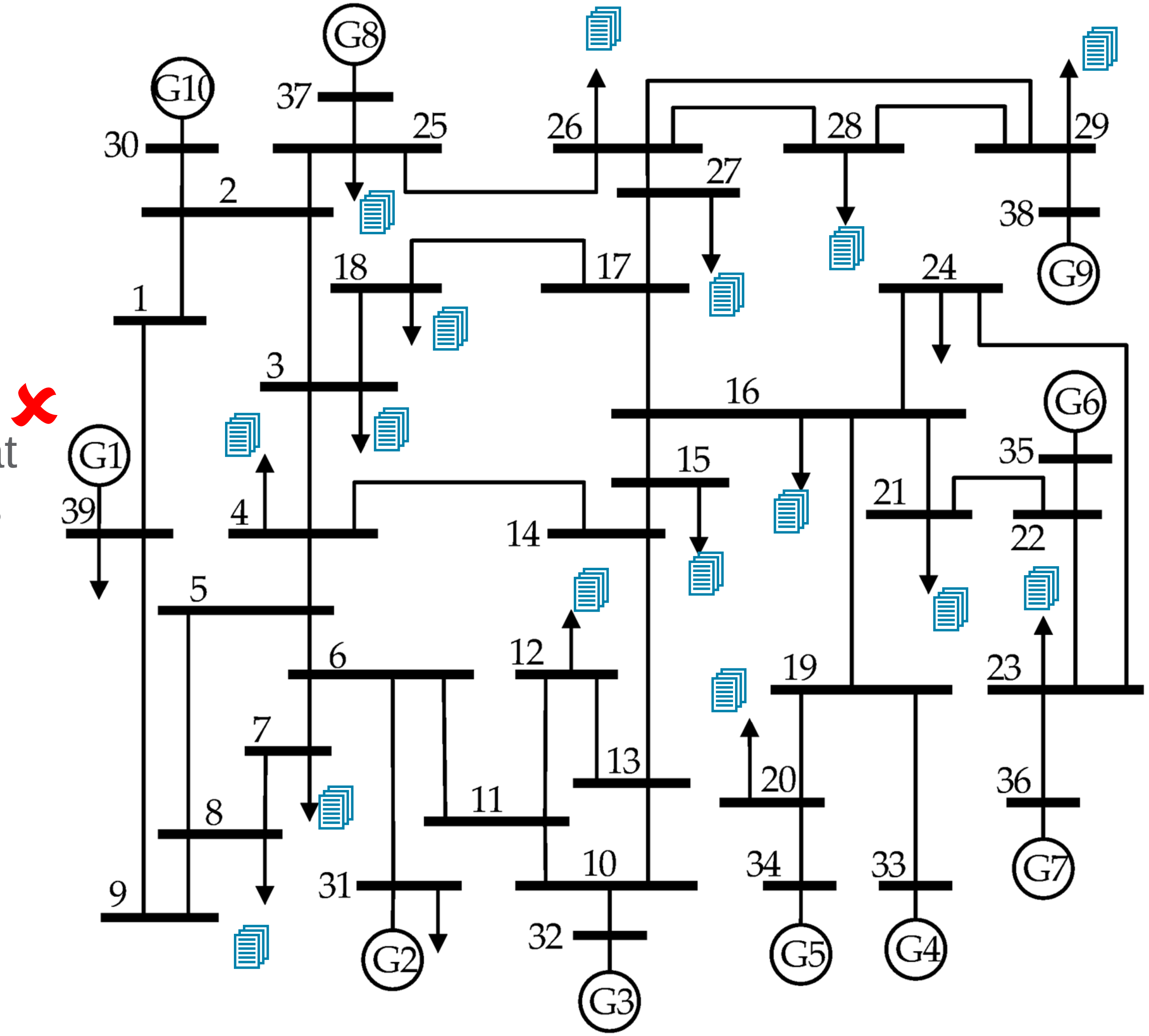
PSSE/HELICS/GridLAB-D Co-Simulation Platform





Test System

Gen Trip at t=12s



- Multiple parallel IEEE 123-Bus Distribution Feeders

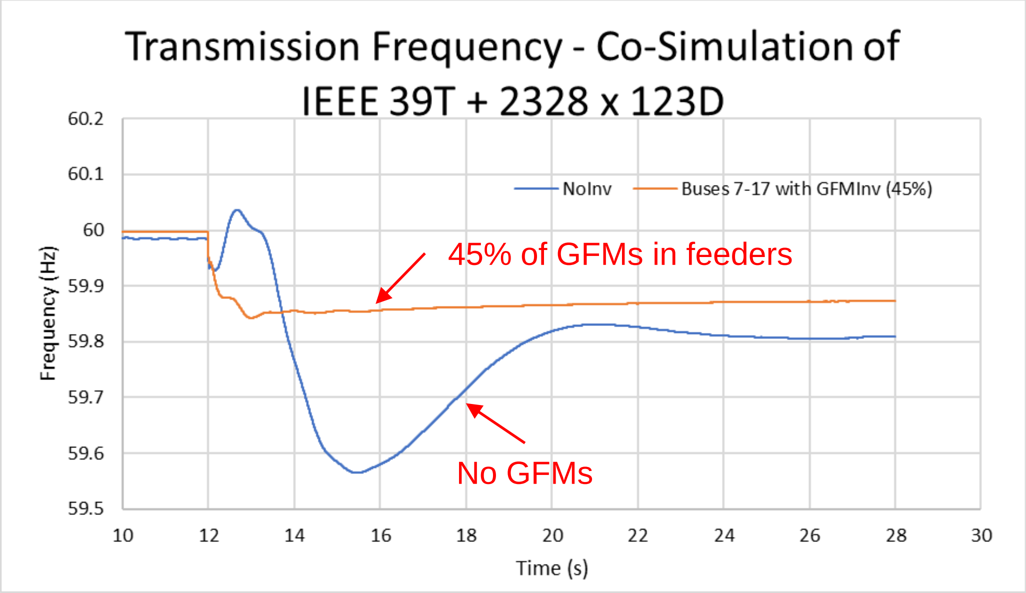
Connected at all load buses except Bus 31 and 39

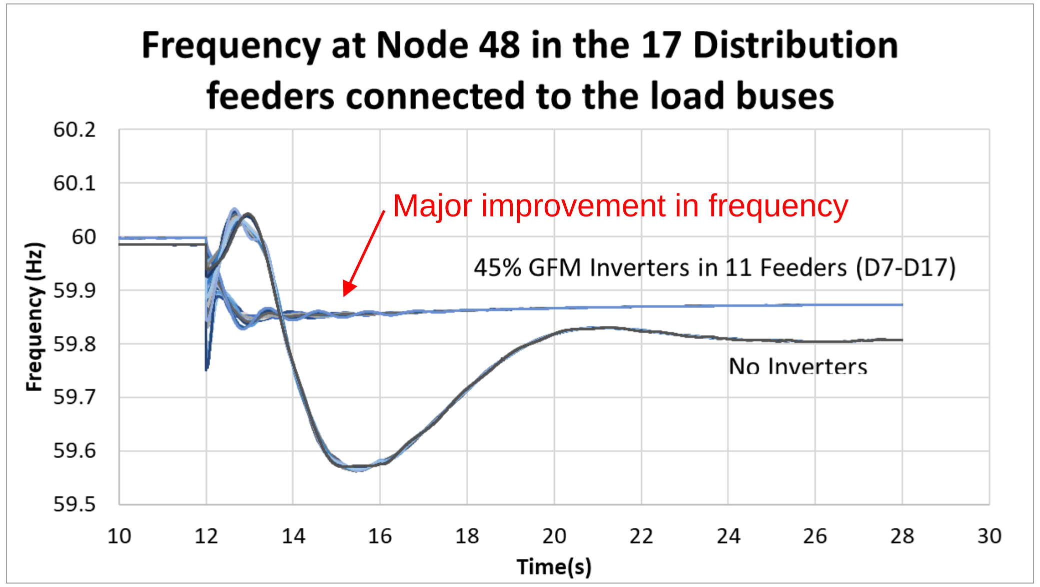
Conclusions:

(following slides)

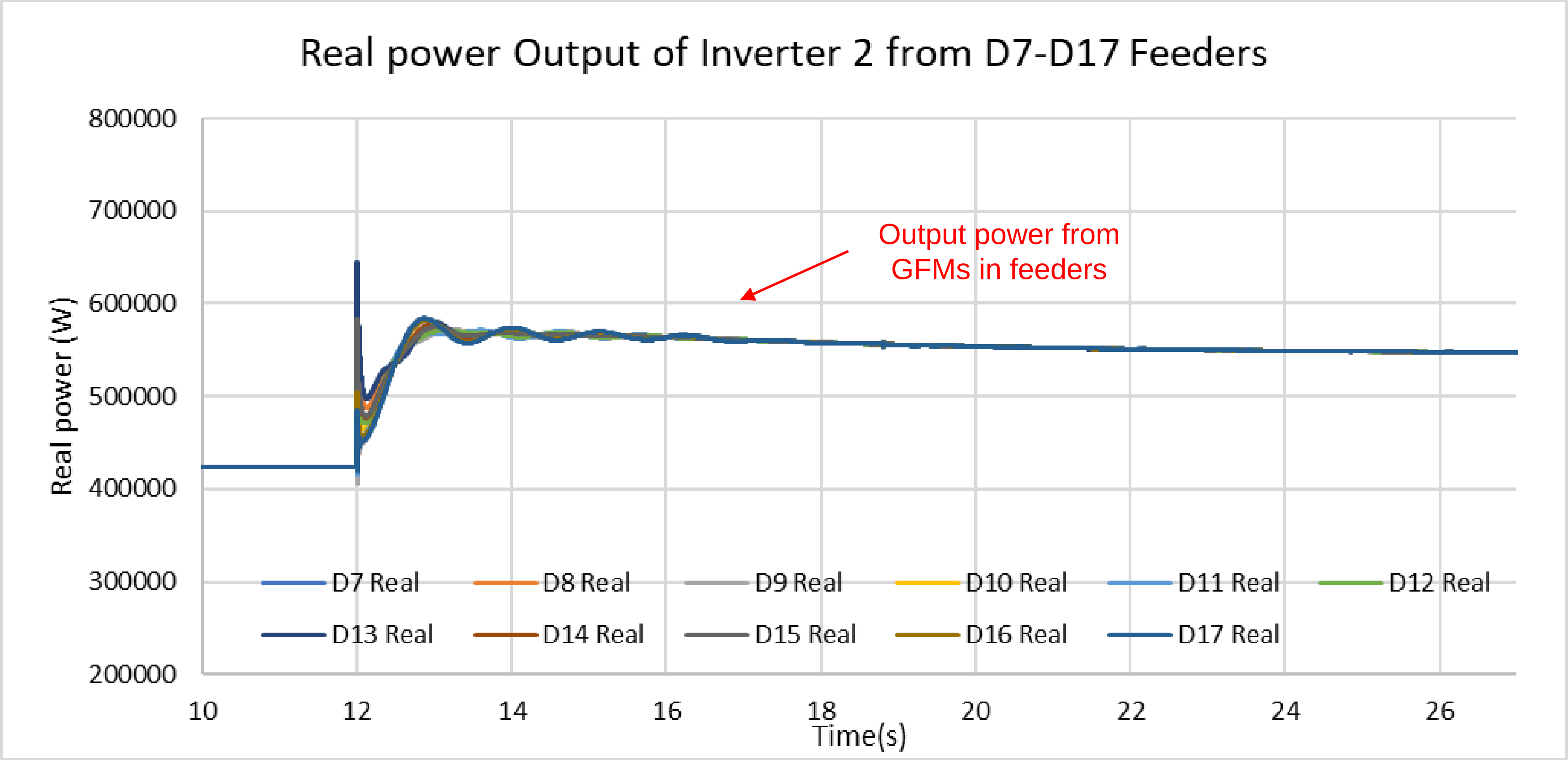
- HELICS enables PSSE and GridLAB-D co-simulation to examine the dynamic stability of T&D systems.
- GFM inverters at the distribution level can improve the primary frequency response of bulk power systems.

Results – IEEE 39 Bus with 17Load Buses Replaced with 123-Bus Feeders



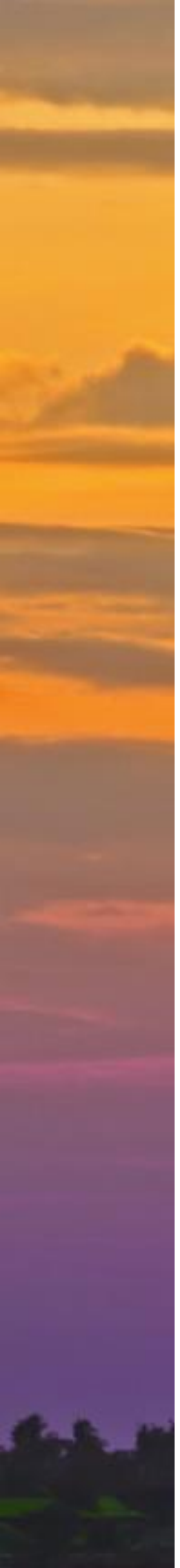


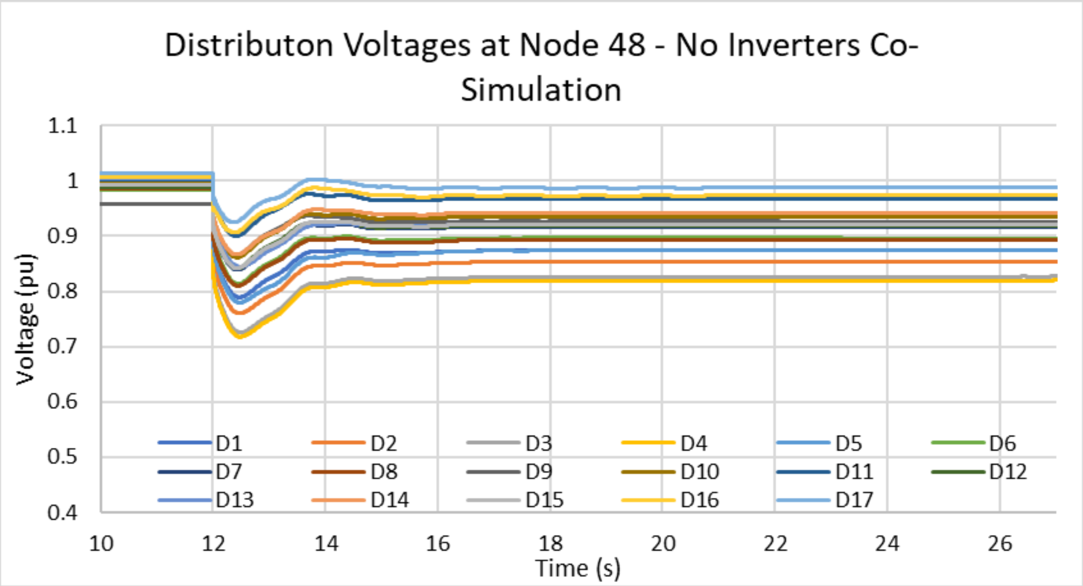
Grid Frequency Regulation

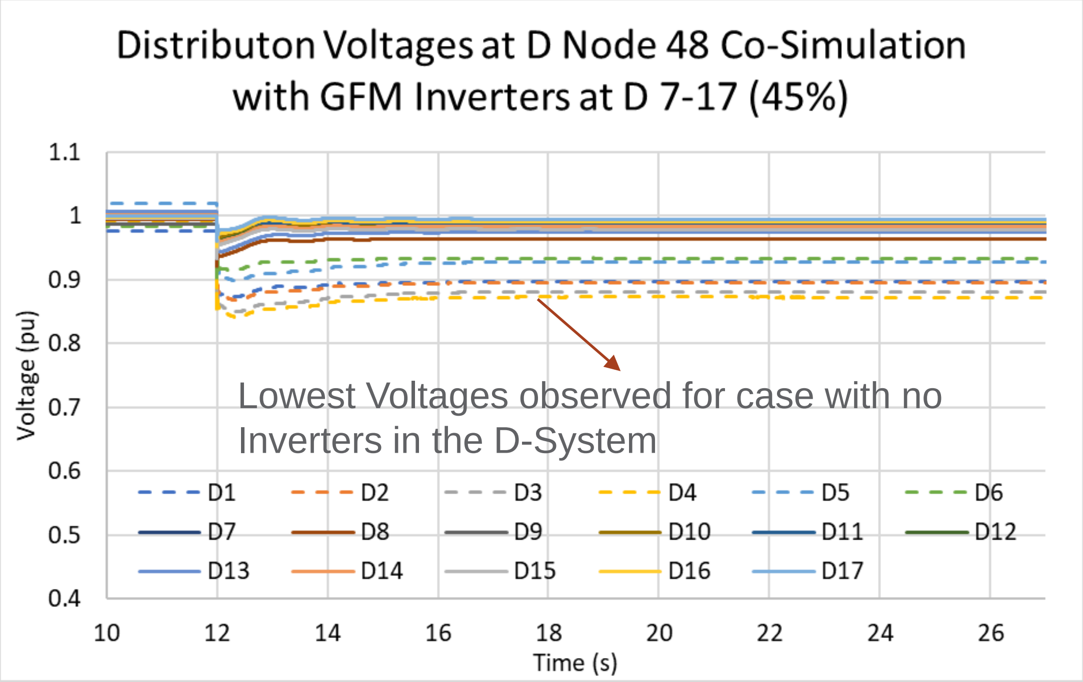


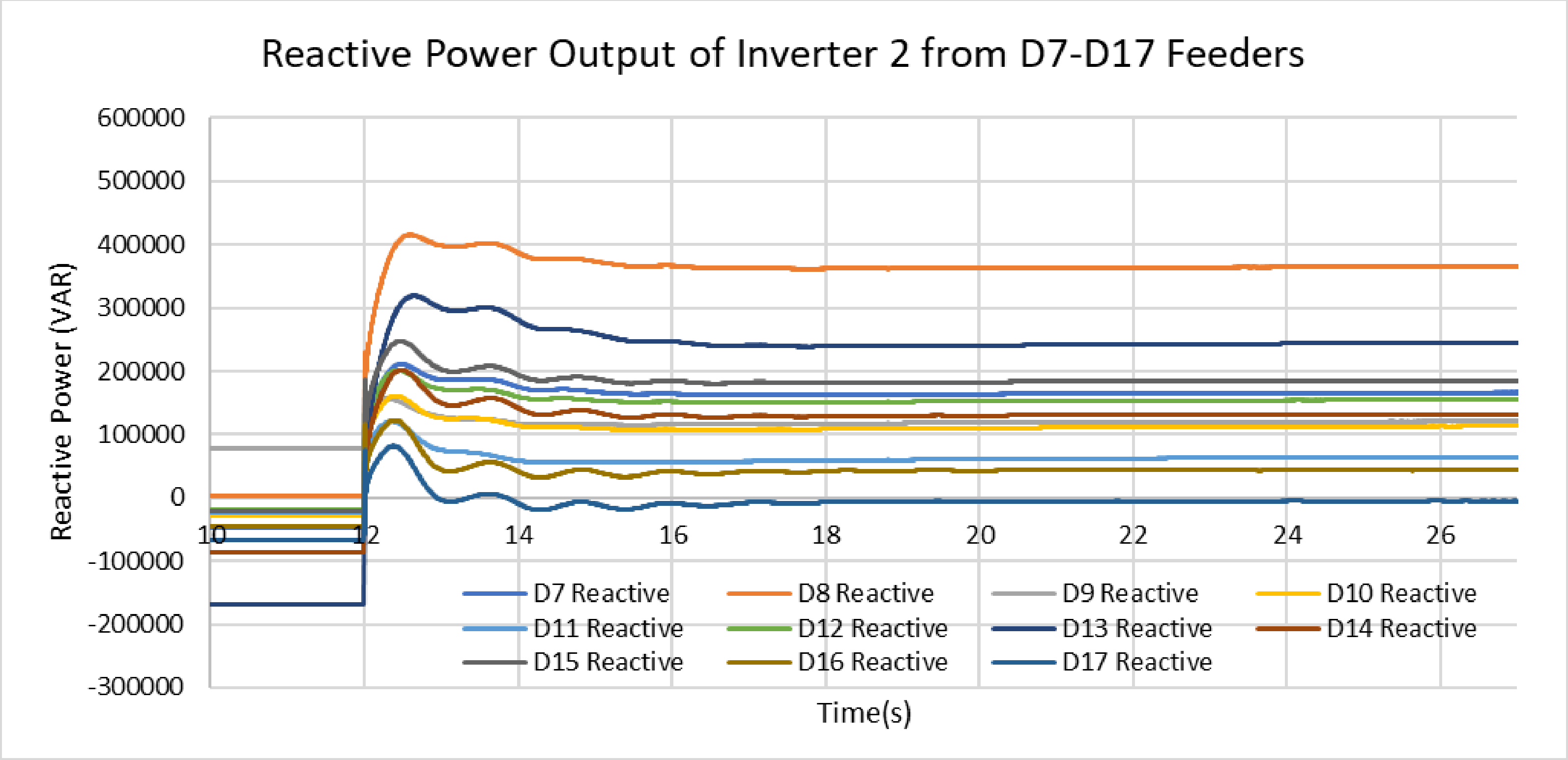
- Significant Improvement on the Grid Frequency NADIR
- Overall Grid Frequency Improvement (Transmission and Distribution Systems)

Distribution Voltage Profile Improvement









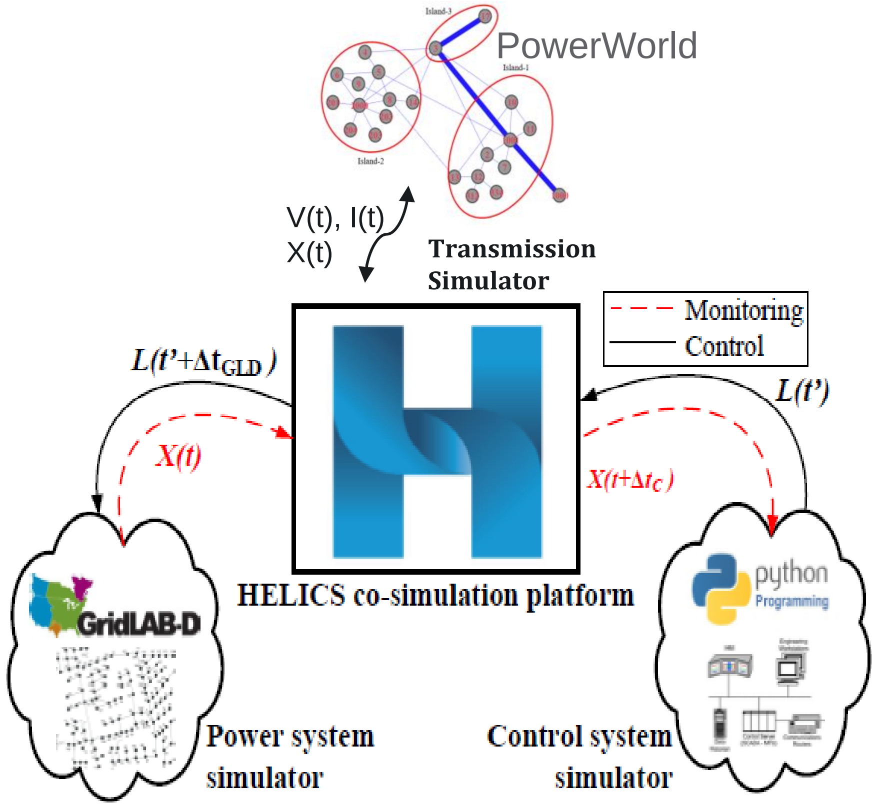
- Overall Improvement in the Voltages in the D-Systems
- For Feeders without Inverters, Voltages were observed to be lowest, however, better profiles due to effect of Inverters in neighboring load buses

CleanStart DERMS

E. Stewart (*PM), J. Fuller (PI), B. Bhattarai, S.N. Gourisetti, A. Singh, J. Joo, V. Donde, C. Coffrin, D. Fobes

Design and deploy a DER-driven mitigation, blackstart, and restoration strategy for distribution feeders.

- Leverage 100% clean DERs to black start during outage.
- Demonstrate in detailed simulation allowing for flexibility and modularity.
- Deploy and test on actual system.



HELICS is being used as a core engine for time coordination between distribution system simulator, sub-transmission, and control system simulators (restoration algorithm, sensors)

CS-DERMS Platform: Modular platform that provides interactions among key components of the real-world power distribution and transmission system grid models, DERs, and controls and sensors to allow testing and demonstration of distributed service restoration using clean DERs

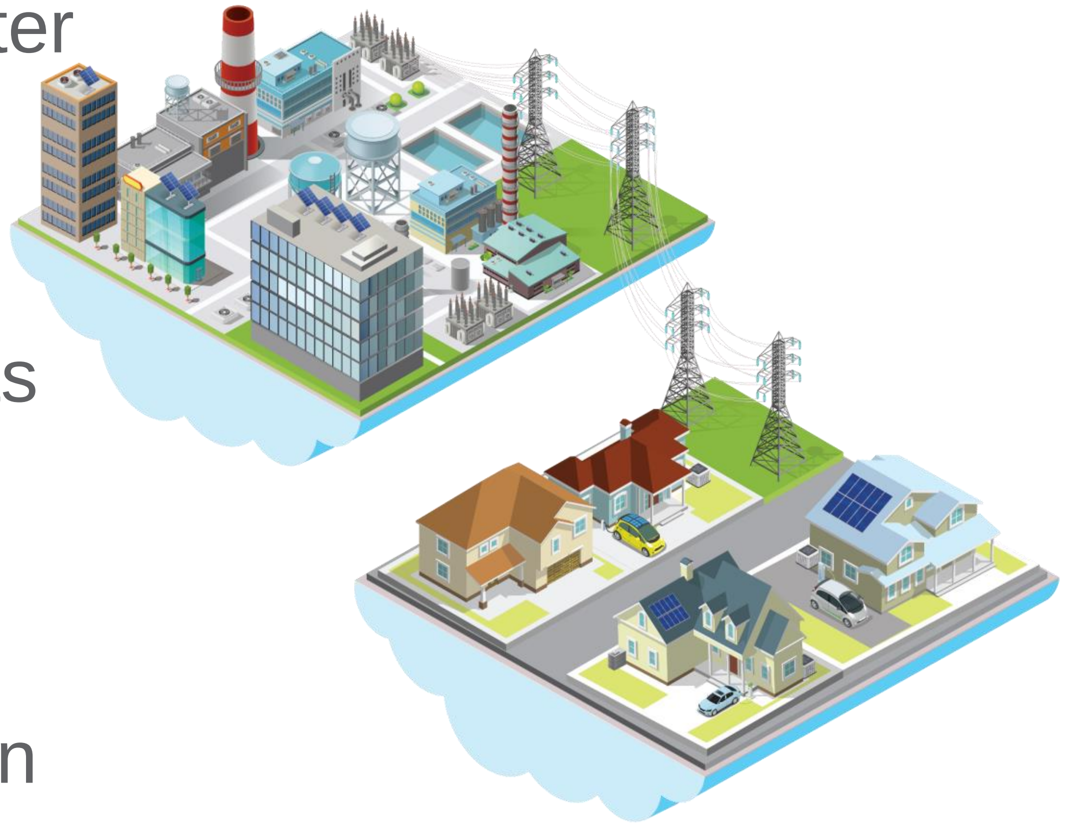
Lawrence Livermore National Laboratory
Pacific Northwest NATIONAL LABORATORY
Los Alamos NATIONAL LABORATORY

Transactive Energy Research

Hayden Reeve (PM), Trevor Hardy (Technical POC)

Energy System Needs:

- Robust and effective load flexibility to enable greater deployment of renewable generation
- Equitable and open participation by DERs (loads, generation, & storage) in the energy system
- Ability to reconfigure DERs during resiliency events to maximize societal access to energy



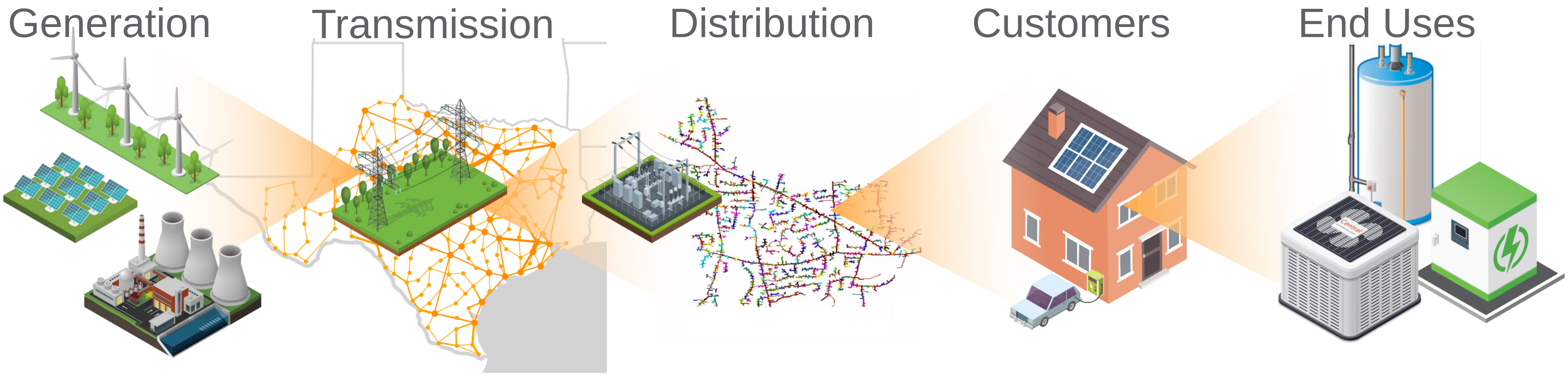
Transactive Energy System Attributes:

- Ensures customer choice and privacy
- Enables efficient, market-based resource allocation
- Distributed decision-making for scalability, ease of integration, and robustness

Global energy goals cannot be met without changes in how we control complex systems

End-Use Integration and Coordination

(and you can extend this platform to any integrated T+D market “control”)



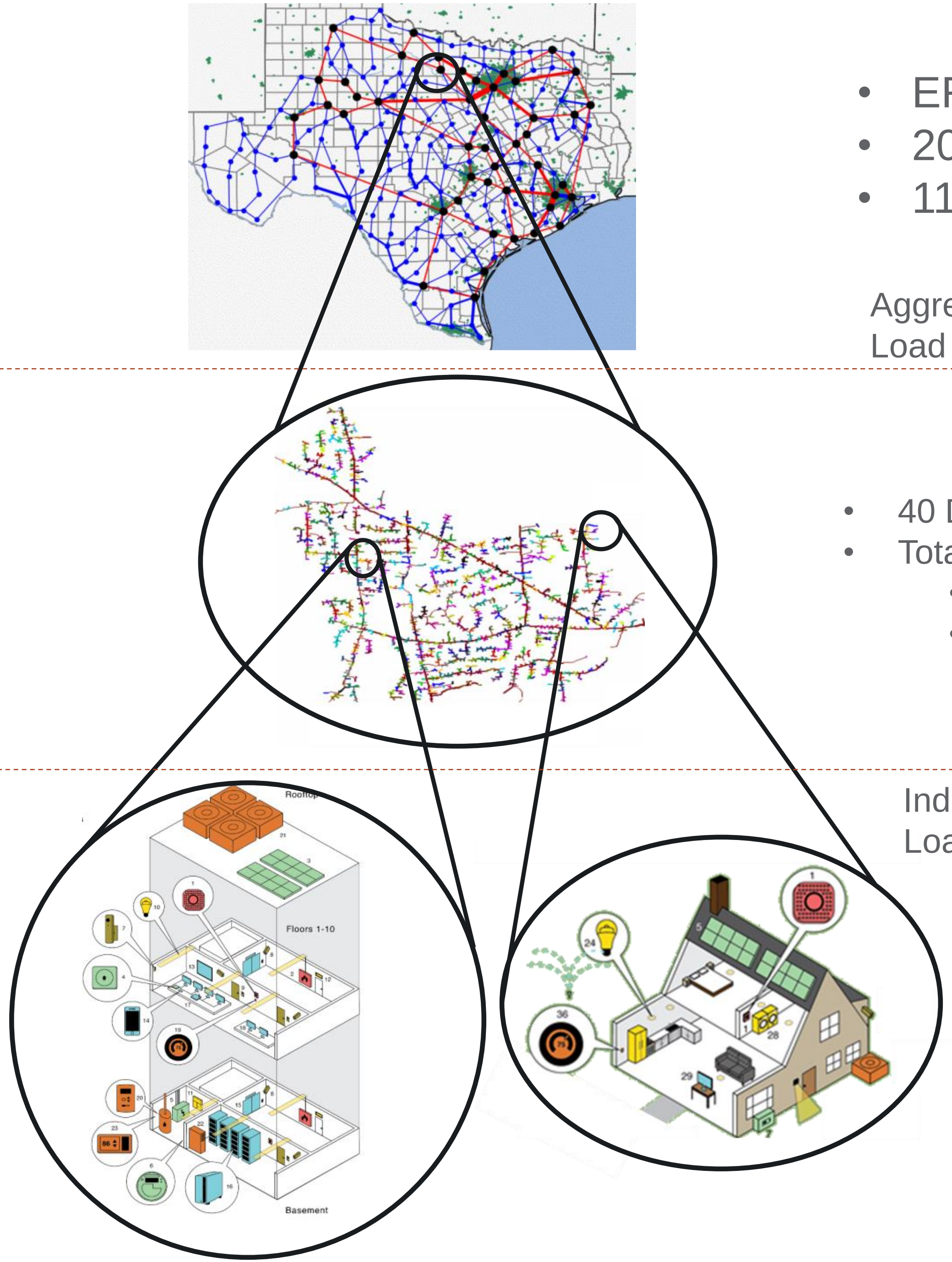
Integrated Dynamic System Model

Control, Coordination, & Market Integration Schemes

Valuation Methodology and Economic Performance

DSO+T Study Scope

Bulk Electricity & Market



- ERCOT-size ISO
- 200 substations
- 110 generators

Aggregate Load ↑ ↓ Wholesale Prices

Distribution System

- 40 Distribution System Operators
- Total of ~82,000 buildings
  - ~76,800 residential buildings
  - ~4,800 commercial buildings

Individual Loads ↑ ↓ Retail Prices

Behind the Meter Devices

- ~89,000 air conditioners
- ~47,000 water heaters
- ~24,000 batteries
- ~20,700 EV chargers
- ~27,000 rooftop PV installations

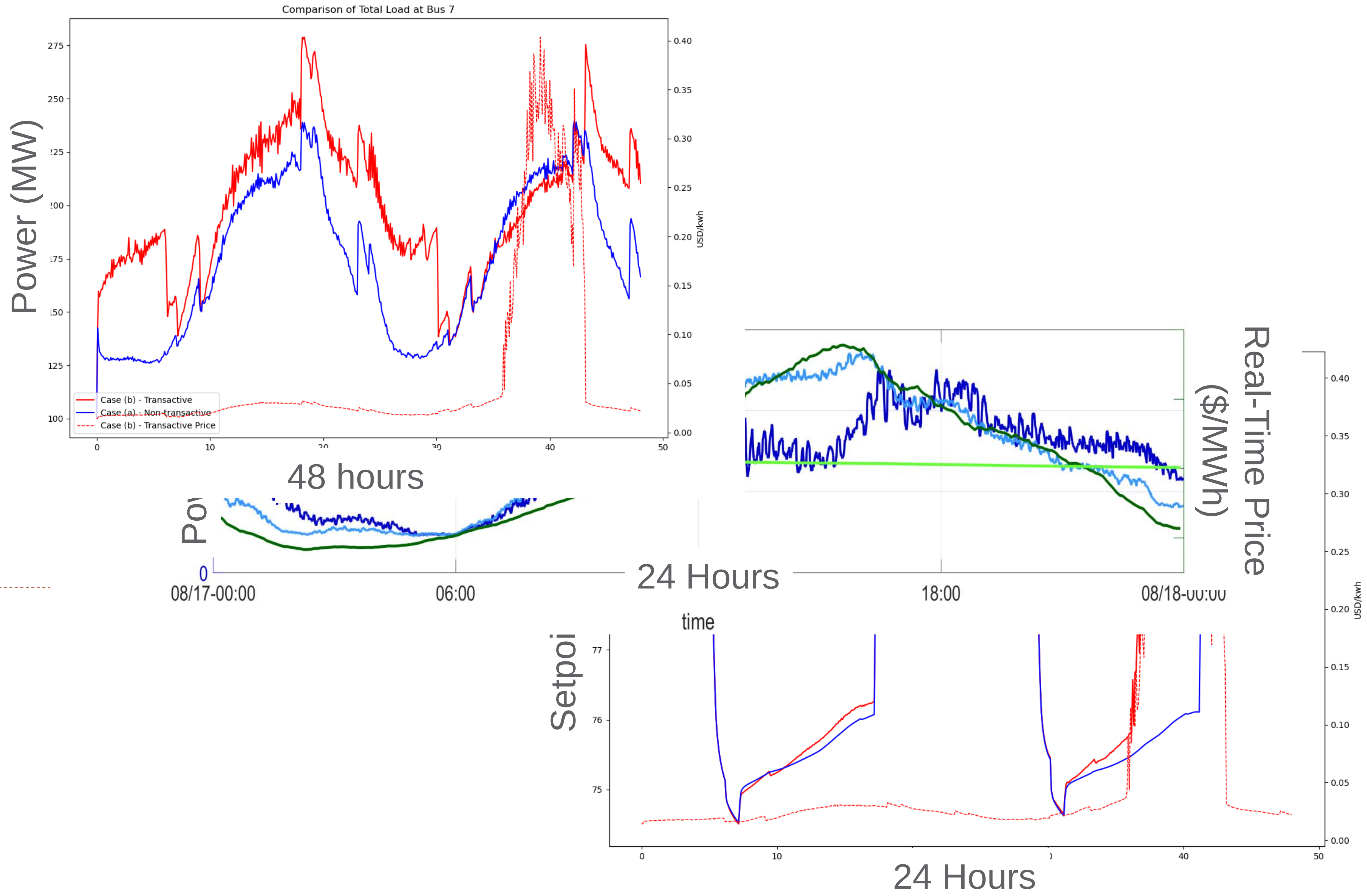
- High fidelity **capability** to simulate customer, distribution, & bulk system operations as coordinated by retail markets linked to wholesale markets
- **Analysis** of the economic operation of a system subjected to moderate & high penetrations of renewable generation with DER flexibility coordinated by Transactive Energy

DSO+T Study Scope

Bulk Electricity & Market

Distribution System

Behind the Meter Devices



HELICS

www.helics.org

Questions?

Contact:
Jason.Fuller@pnnl.gov
Zhenyu.Huang@pnnl.gov