20 YEARS 2006 TO 2026

ELECTRICITY INFRASTRUCTURE OPERATIONS CENTER

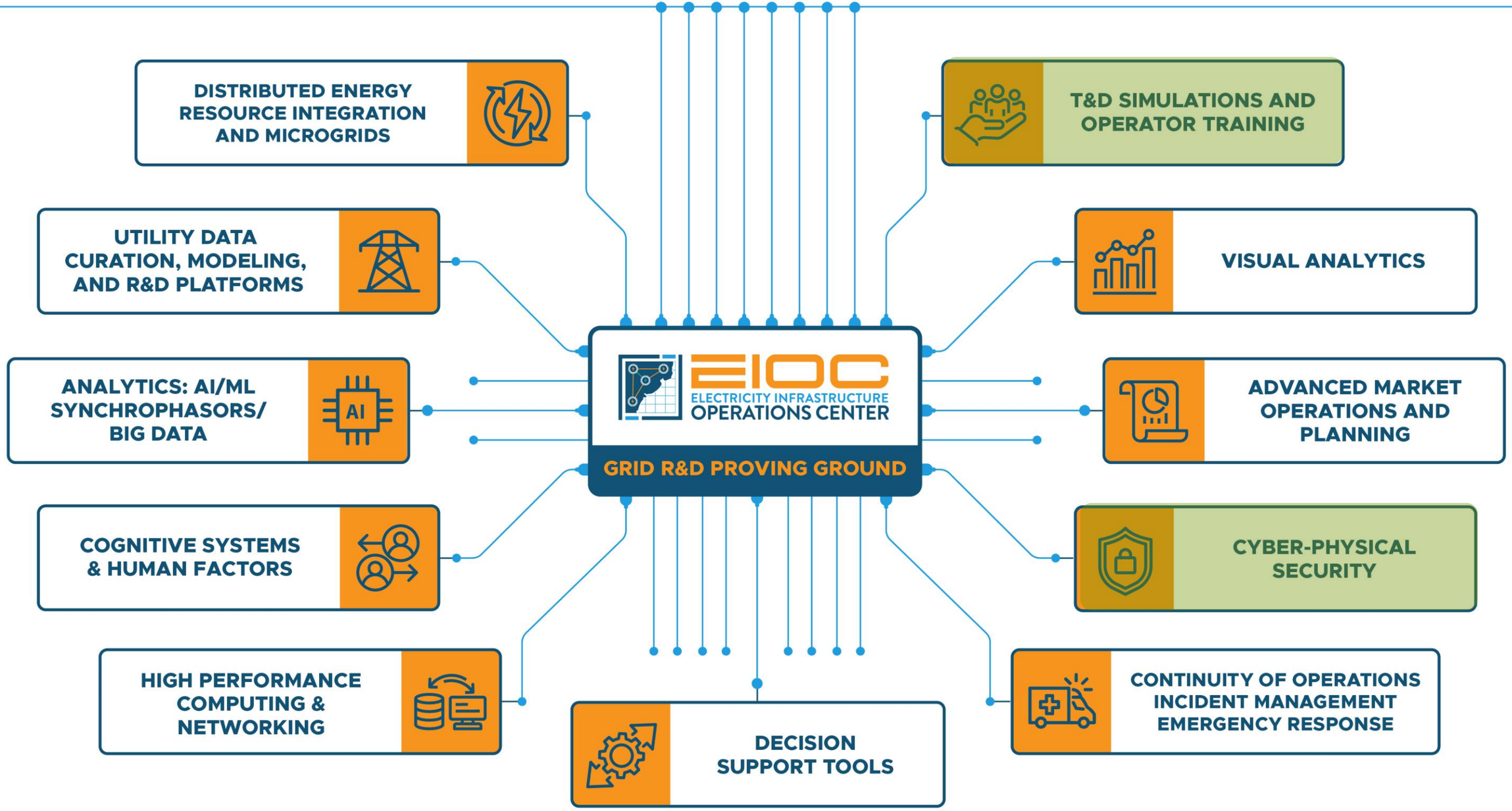
WEBINAR SERIES 2026

Shaping Tomorrow's Grid: T&D Co-Simulation for Control Rooms

February 24, 2026

Burhan Hyder

Manisha Maharjan


DISTRIBUTED ENERGY RESOURCE INTEGRATION AND MICROGRIDS
T&D SIMULATIONS AND OPERATOR TRAINING
UTILITY DATA CURATION, MODELING, AND R&D PLATFORMS
VISUAL ANALYTICS
ANALYTICS: AI/ML SYNCHROPHASORS/ BIG DATA
AI
EIOC
ELECTRICITY INFRASTRUCTURE OPERATIONS CENTER
GRID R&D PROVING GROUND
ADVANCED MARKET OPERATIONS AND PLANNING
COGNITIVE SYSTEMS & HUMAN FACTORS
CYBER-PHYSICAL SECURITY
HIGH PERFORMANCE COMPUTING & NETWORKING
DECISION SUPPORT TOOLS
CONTINUITY OF OPERATIONS INCIDENT MANAGEMENT EMERGENCY RESPONSE

Pacific Northwest
NATIONAL LABORATORY

Shaping Tomorrow's Grid: T&D Co-Simulation for Control Rooms

Burhan Hyder
Cybersecurity Engineer

Manisha Maharajan
Electrical Engineer

U.S. DEPARTMENT of ENERGY BATTELLE

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

Pacific Northwest
NATIONAL LABORATORY

Burhan Hyder
Cyber-Physical Security Engineer

Burhan’s research focuses on smart grid cyber-physical security, including anomaly detection, risk assessment, and hardware-in-the-loop testbeds. He holds a Ph.D. in Electrical Engineering.

Manisha Maharjan
Electrical Engineer

Manisha’s research focuses on power system modeling, power system dynamics, distribution system modeling, and machine learning applications in power systems. She holds a Ph.D. in Electrical Engineering.

Agenda

- Transmission and Distribution System Operations Overview
- Why T&D Co-simulation
- PRIME Testbed Overview
  - Capabilities
  - Features
  - Automation for Model Conversion and Communication Configuration
  - Use-cases
  - Deep dive: T&D Co-simulation with Energy Management System (EMS)/Advanced Distribution Management System (ADMS)
  - Cybersecurity Scenario
- Conclusion

EMS/ADMS Overview

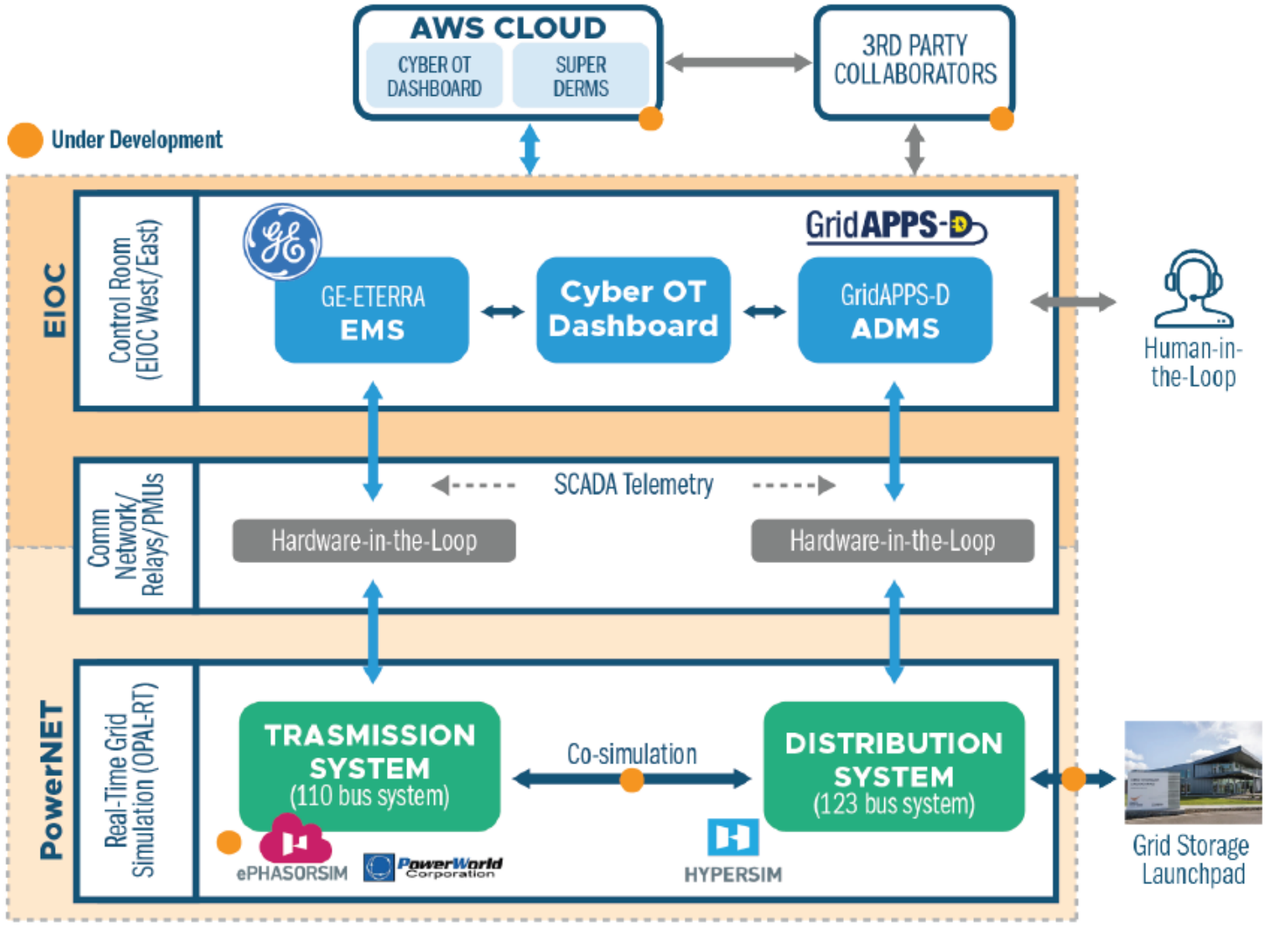
- **EMS (Transmission):** Bulk grid monitoring + dispatch; maintains reliability (flows, frequency, contingencies).
- **ADMS (Distribution):** Feeder operations + switching/voltage/outage management
- **IBR growth on distribution:** PV/storage/loads can rapidly change net load at substations.
- **Transmission visibility gap:** EMS often sees only aggregate measurements at the T&D interface, not feeder-level DER availability/status.
- **More uncertainty:** DER variability + distribution actions increase real-time ramps and day-ahead forecast error.

Why T&D Co-simulation

- **Capture impacts of D on T:** Feeder switching, DER trips, volt/VAR controls can change substation P/Q and affect transmission.
- **EMS + ADMS in the loop:** Test coordination using real telemetry/commands (measurements, AGC/setpoints).
- **Validate T&D data-sharing tools:** Evaluate performance with realistic timing, models, and event conditions.
- **Operational credibility:** Use cases and metrics informed/validated with utility and ISO models.

PRIME Testbed

- **What PRIME is:** A layered, real-time T&D co-simulation and control-room test environment designed to study operations and cybersecurity across the T&D boundary.
- **Why it matters:** It bridges high-fidelity power simulation with realistic control, communications, and operator-in-the-loop workflows, so technologies can be tested in conditions closer to real operations.



Key Capabilities

- **Real-Time Grid Simulation:**
  - Real-time T&D co-simulation using simulators such as OPAL-RT and PowerWorld Dynamic Studio.
- **Communication Network:**
  - C-PHIL with substation hardware (Relays, PMUs, RTACs) and hybrid virtual + physical networking.
- **Control Center Layer:**
  - Emulates utility-to-ISO control hierarchies; hosts EMS/ADMS and OT cybersecurity visualization (OTVD).
- **Cloud Applications:**
  - AWS-hosted analytics/apps that stream data from EMS, ADMS, and the cyber-OT dashboard.

Key Features

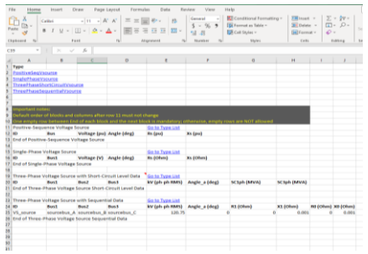
- **Fidelity:**
  - Phasor-domain transmission + EMT-domain distribution models for high-fidelity real-time co-simulation.
- **Flexibility:**
  - Mix-and-match simulation tools and control applications across vendors to fit different research needs.
- **Modularity:**
  - Layered design lets you swap models/tools/apps while preserving interface interactions.
- **Scalability:**
  - Scale T&D models to a few thousand buses without losing fidelity or control-app performance.
- **Accessibility (under development):**
  - Streamlined third-party collaboration via a master scope of work/master CRADA.

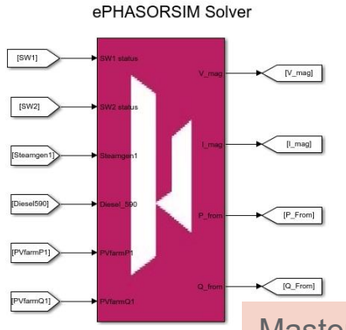
Automated model conversion with communication configuration

- Enables large-scale in real time and multi-rate co-simulation for T&D networks
- Generates ready-to-run scenarios for 1- to 10-ms time-step simulations
- Supports HIL testing under real-time dynamic conditions
- Automated model conversion-Directly model import using OPAL-RT UDB
  - PowerWorld/PSSE/PSLF-positive sequence phasor-based tool
  - PowerFactory/ CYME- distribution system modeling

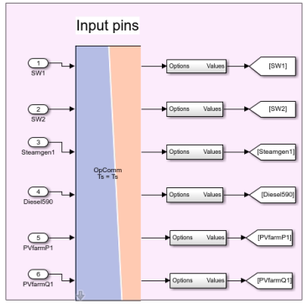
ePHASORSIM | Electro-Mechanical Phasor In OPAL-RT Simulator (real-time)

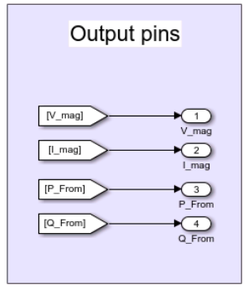
-Network model in excel
-Direct import from third party

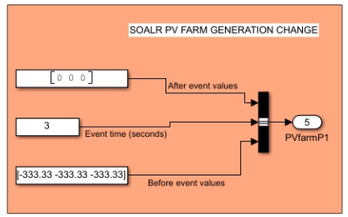


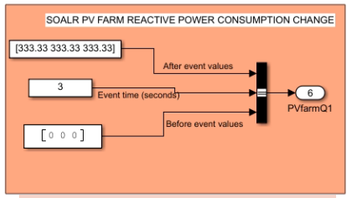


Master block

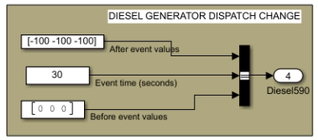


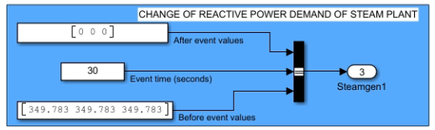






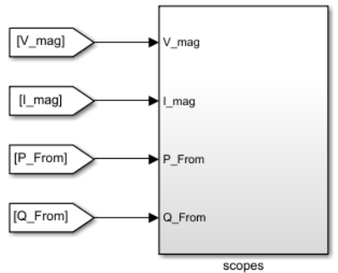
Input commands

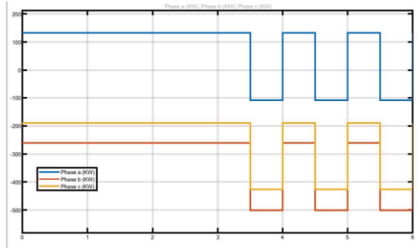




Console block

Output response





Automated Model Integration Process

ePHASORSIM
Electro-Mechanical Phasor In OPAL-RT Simulator (real-time)

110-bus Transmission System

ePHASORSIM

Network Data

direct network import

Pins
- Measurement probes
- Control signals

Visualization- Additional output probes e.g. transformer P/Q

PowerWorld Corporation

PSS®E cyme

DNP3 Communication Configuration

PARSER
-Parse out DNP3 communication pins from SCADA/EMS
-Generate DNP3 communication pins with ePHASORSIM naming convention

MAPPING
-Create DNP3 data connections from model parameters to IO pins
-RT-Lab DNP3 configurations using Python API

Transmission System Operator

SCADA

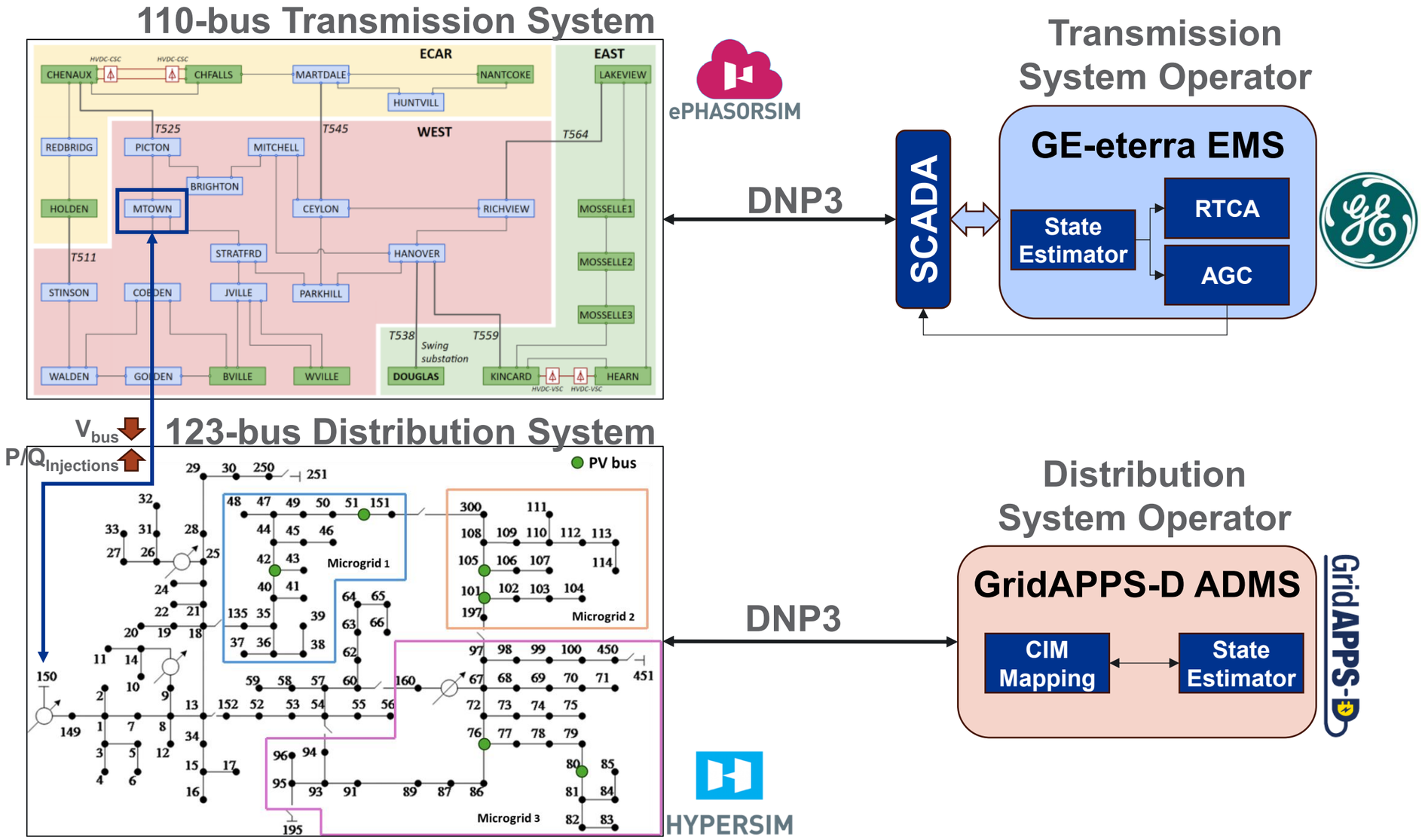
GE-eterra EMS
- State Estimator
- RTCA
- AGC

- Streamlined process for model conversion for T&D co-simulation in real-time
- Reduces integration time, preserves fidelity

Use-Cases

- **Technology Validation & Demonstration**
  - Develop/test tools across the T&D boundary; improve readiness (higher TRLs)
  - Generate realistic, repeatable T&D co-simulation datasets for evaluation
- **Operator Training**
  - Use EIOC control-room environment with real-time PRIME data streams
  - Train operators/engineers/cyber analysts (Distribution, Transmission, BA, RC)
- **Human Factors Testbed**
  - Human-in-the-loop studies of new T&D tools using high-fidelity, real-time scenarios
  - Measure how tool design impacts operator workload, adoption, and performance
- **Testbed Federation**
  - Connect PRIME with other testbeds across cloud, control/cyber, and HIL simulation layers
  - Support internal/external federations (e.g., PowerNET, PNNL-NLR HIL federation)

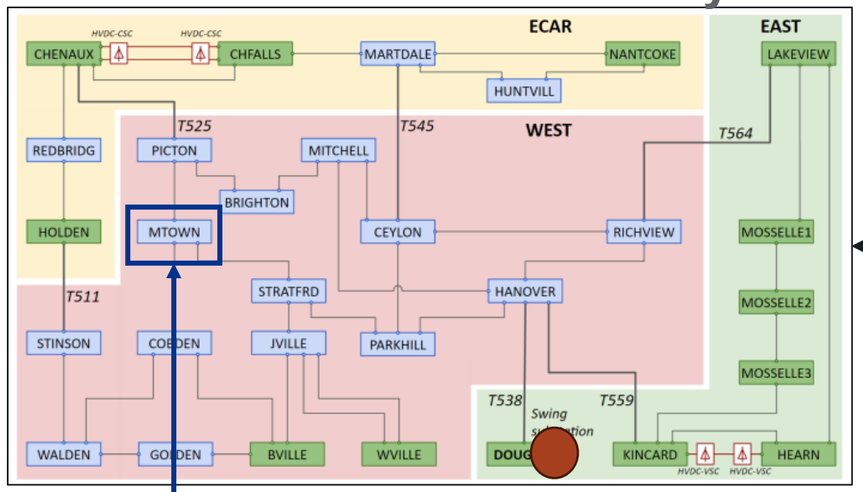
Use-case Deep Dive: T&D Co-Simulation with EMS/ADMS-in-the-Loop

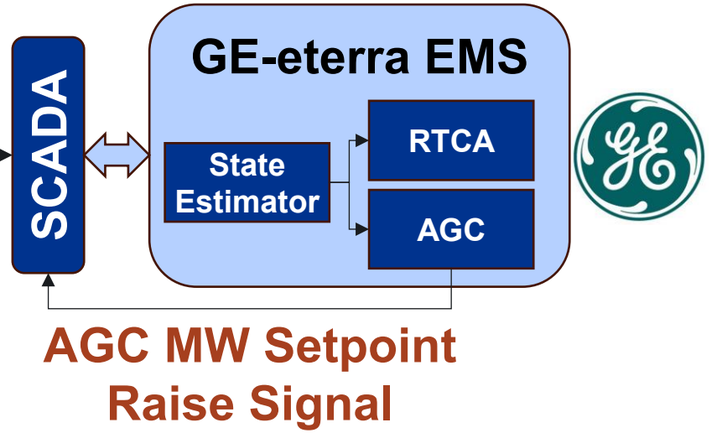


Physical Scenario: Generator Trip in EAST Area

Generator Trip

110-bus Transmission System



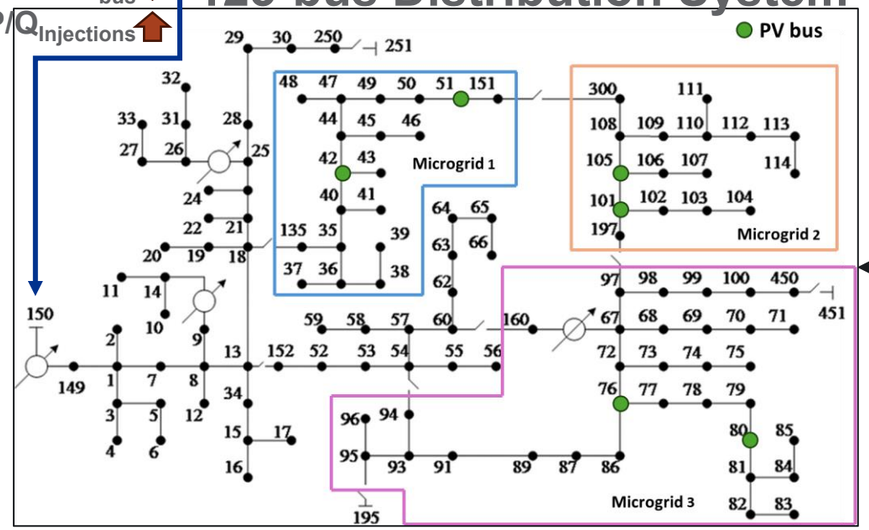


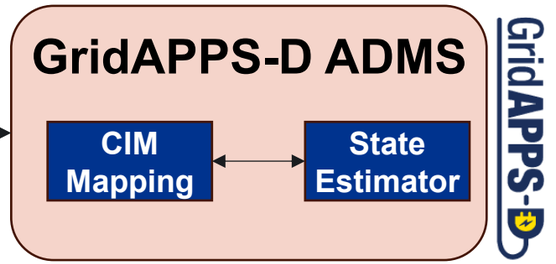
AGC MW Setpoint
Raise Signal

V_{bus}

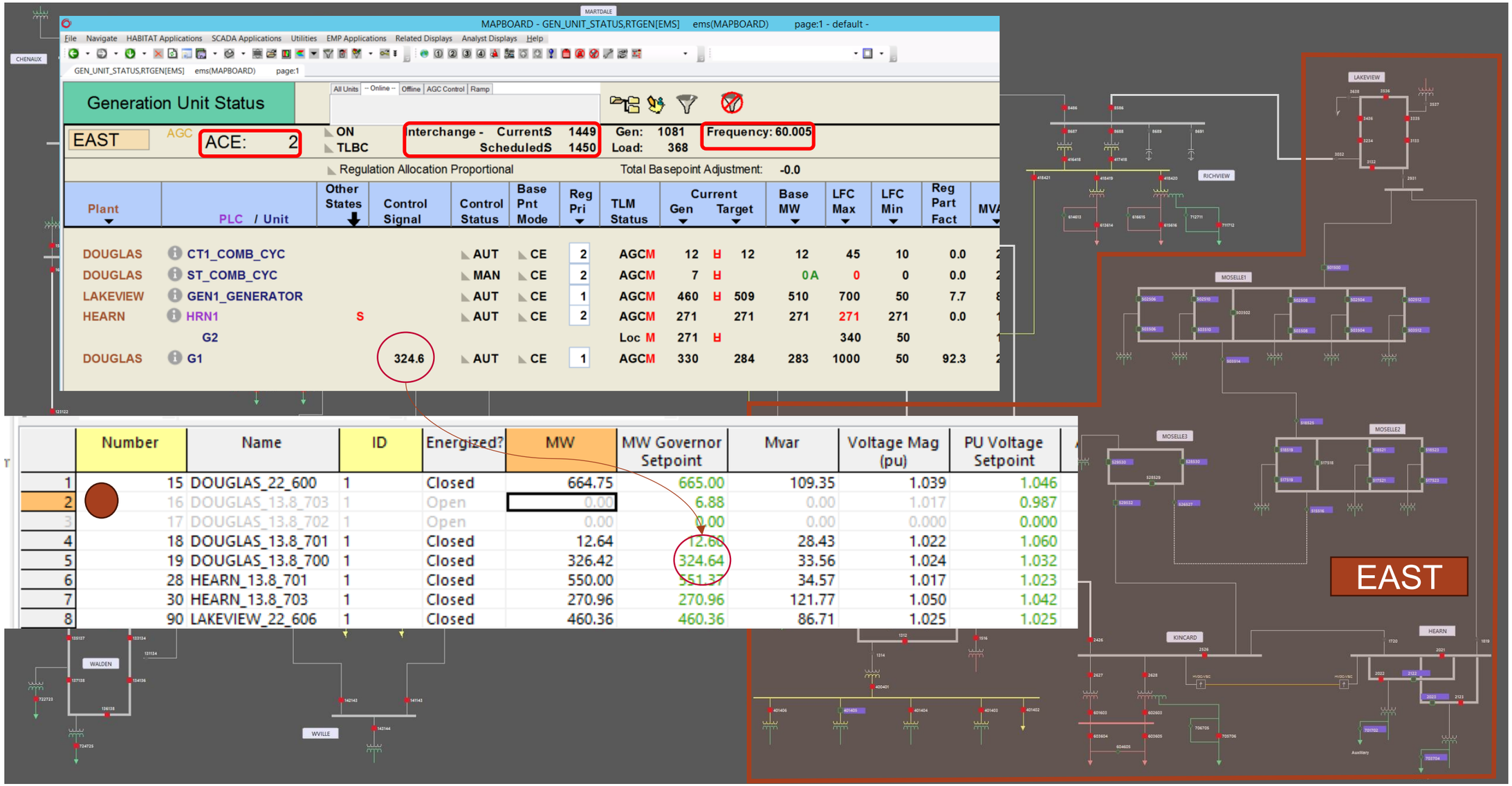
$P/Q_{Injections}$

123-bus Distribution System

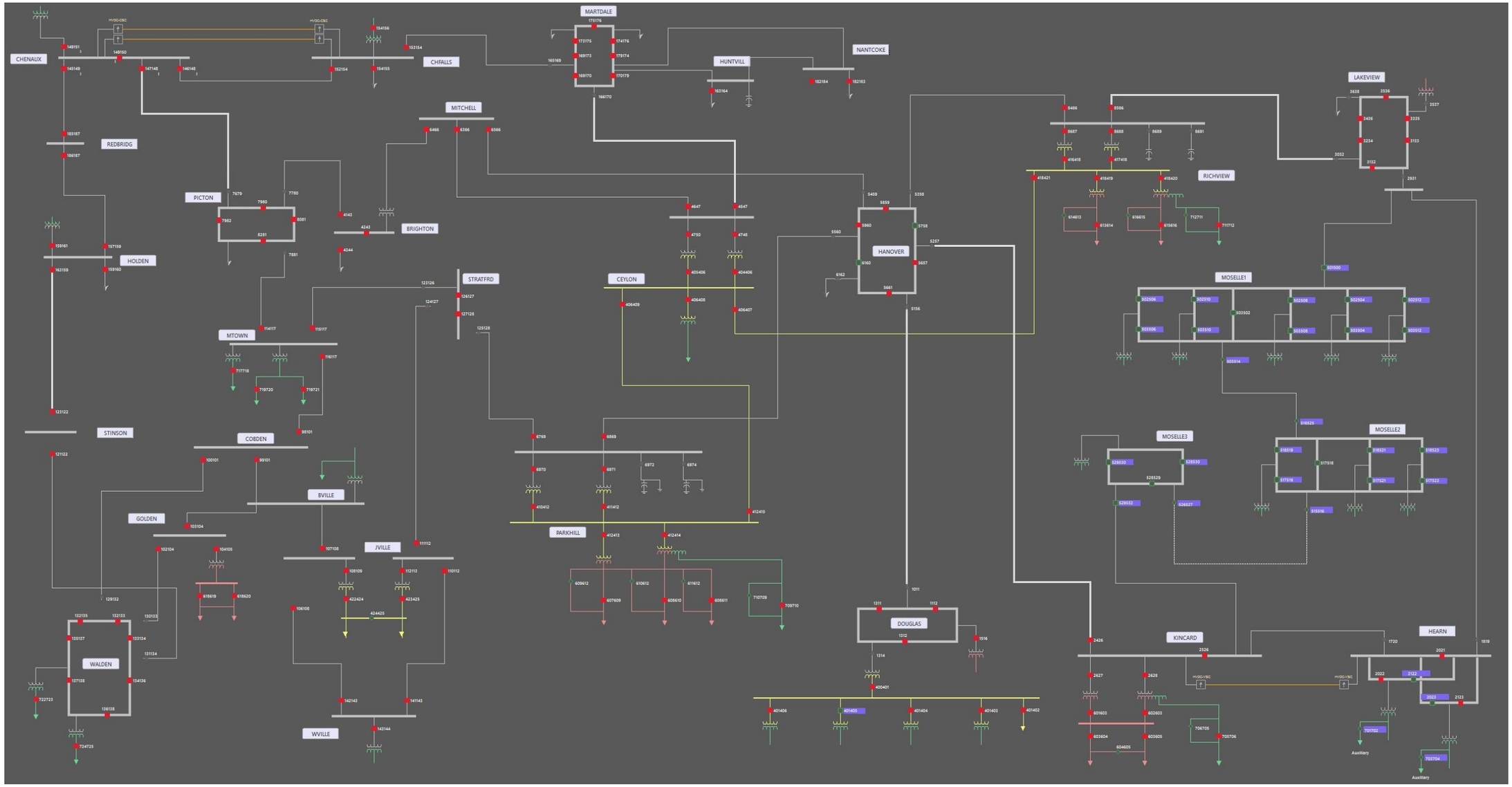




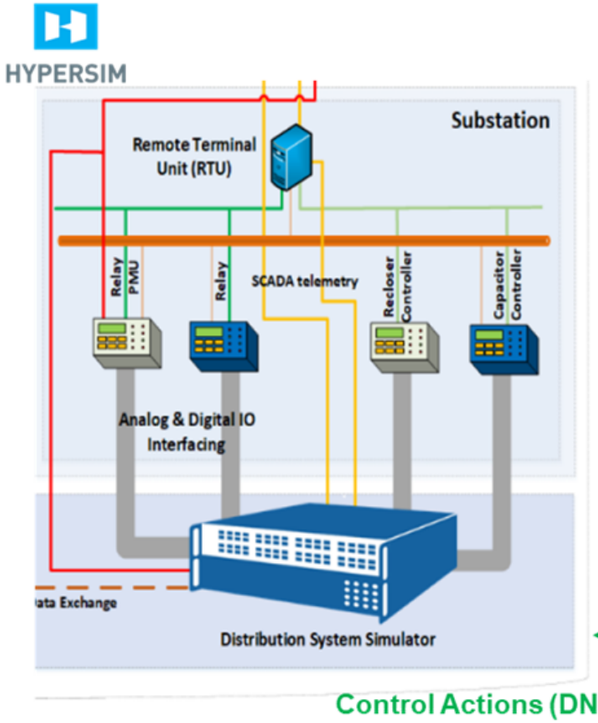
AGC Operation in the EMS



AGC Operation in the EMS



ADMS (GridAPPS-D) Workflow and Integration



GridAPPS-D

Load equivalent model in GridAPPS-D model dictionary

Mapped DNP3 measurement indices to corresponding model mRIDs

Initial network configuration for GridAPPS-D DNP3 service (ip, port, etc.)

DNP3 Field Data

GridAPPS-D DNP3 service polls measurements every 30 s

Measurements converted to CIM messages using mapping

CIM messages sent to field output topic to make them available to all applications (eg: State Estimator) and visualization.

SOE handler processes DNP3 measurements in Analog/Binary format and makes them available to the application layer

Applications process messages and issue operating actions to field input topic

CIM messages created for actions

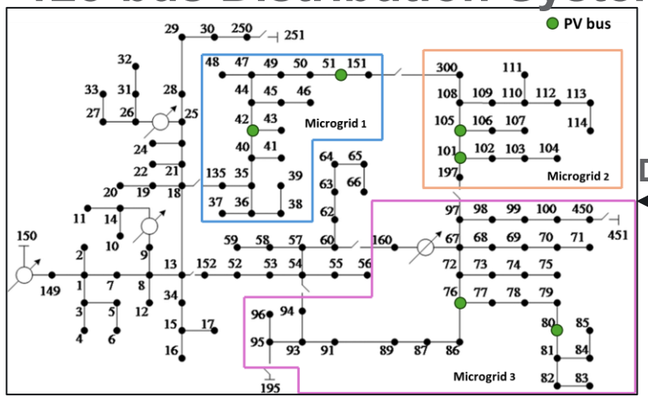
CIM messages converted to DNP3 data for outstation control

Control Actions (DNP3)

GridAPPS-D CIM Messages and DNP3 Measurements

Pacific Northwest NATIONAL LABORATORY

123-bus Distribution System



DNP3

GridAPPS-D

GridAPPS-D ADMS

CIM Mapping ↔ State Estimator

<pydnp3.opendnp3.ICollectionIndexedBinaryOutputStatus object at 0x7fd65fc8b768>
<pydnp3.opendnp3.ICollectionIndexedAnalog object at 0x7fd65fc8b768>
index 0 value 0.002359675941988826
index 1 value 0.0025426114443689585
index 2 value 0.002626407891511917
index 3 value 2479.33544921875
index 4 value 2470.96630859375
index 5 value 2484.587890625

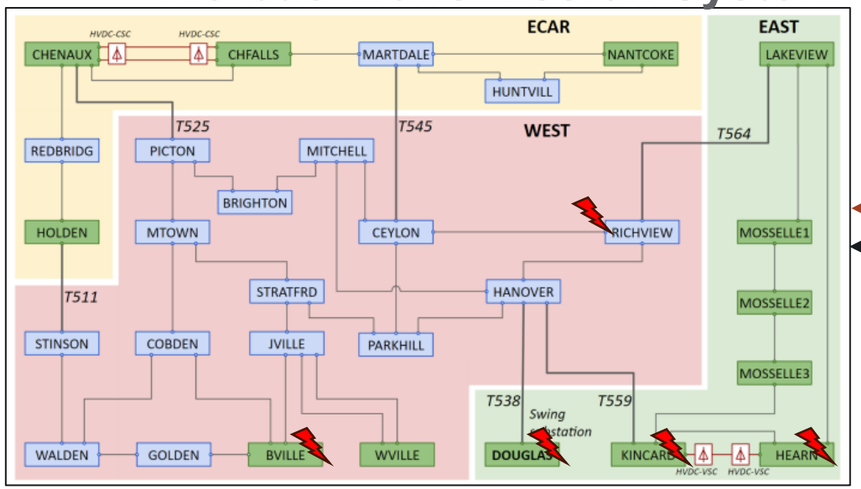
DNP3 Measurements

CIM messages

CIM {'simulation_id': 1234,
'timestamp': '1676600618',
'message':
{'measurements':
{'_a82b9b09-3522-4ac8-9090-e63788310a41':
{'mrid': '_a82b9b09-3522-4ac8-9090-e63788310a41', 'magnitude': 2495.07568359375, 'angle': 0},
'_1258c22f-4321-49a2-ba59-31e029b3ecfb':
{'mrid': '_1258c22f-4321-49a2-ba59-31e029b3ecfb', 'magnitude': 2497.984619140625, 'angle': 0},
'_511daba3-3ad2-4497-90a1-d3297445e63c':
{'mrid': '_511daba3-3ad2-4497-90a1-d3297445e63c', 'magnitude': 2502.950927734375, 'angle': 0},…}}

Cyber Scenario: Loss of RTU Communication

110-bus Transmission System



Hybrid Wide-Area Network Emulation (Virtual + Physical)

DNP3

DNP3

Cyber Anomaly Injection

TSO Control Room

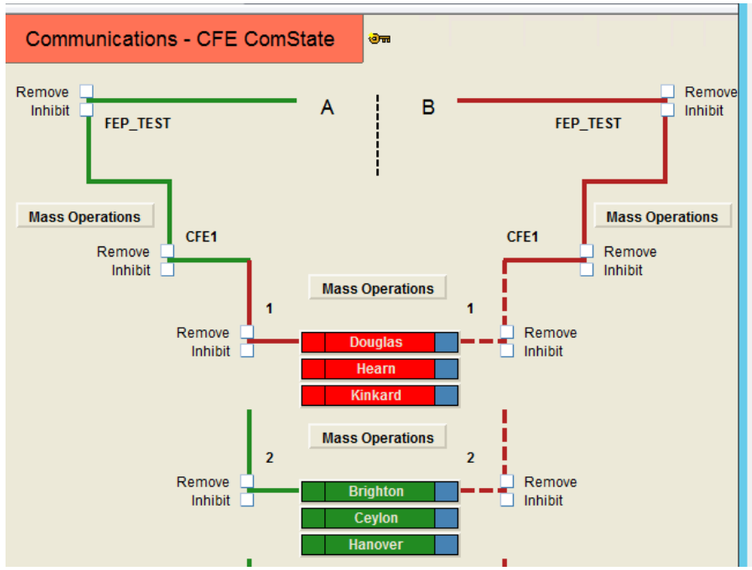
SCADA

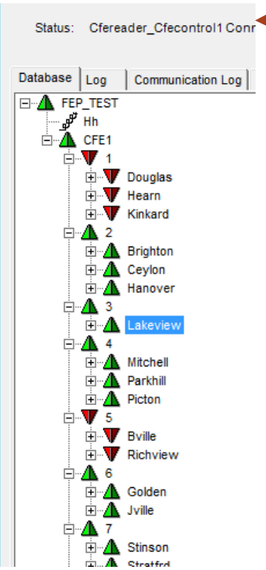
GE-eterra EMS

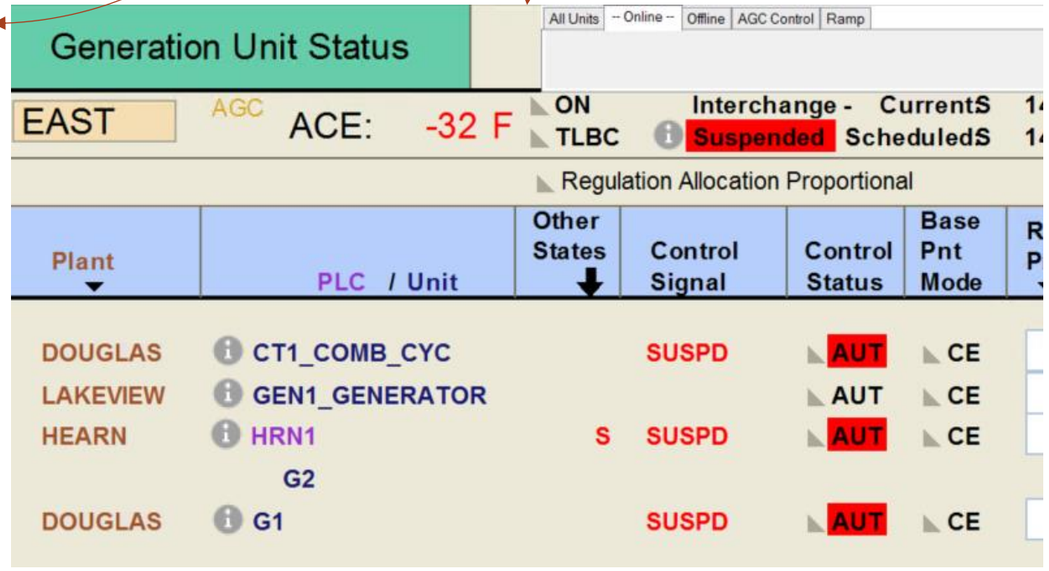
State Estimator

RTCA

AGC







Conclusion

- **T&D Co-simulation is critical** for bridging operational gaps between EMS and ADMS, improving grid reliability and resilience.
- **PRIME Testbed enables realistic, high-fidelity testing** of technologies, workflows, cybersecurity tools across the transmission-distribution boundary.
- **Operator training and human-in-the-loop studies** ensure tools are validated under real-world conditions and improve decision-making.
- **Technology readiness and collaboration** accelerate deployment of advanced grid solutions and foster industry partnerships.
- **Future work**: Expand testbed federation and accessibility for broader industry engagement.

20 YEARS 2006 TO 2026

EIOC

ELECTRICITY INFRASTRUCTURE OPERATIONS CENTER

WEBINAR SERIES 2026

Q&A

Burhan Hyder

Manisha Maharjan

20 YEARS 2006 TO 2026

EIOC

ELECTRICITY INFRASTRUCTURE OPERATIONS CENTER

WEBINAR SERIES 2026

Next Webinar!

Centering the Human in Control Rooms: *How Human Factors Studies Enable Better Performing Tools and Training for Utility Operators and Dispatchers*

March 25, 2026

Corey Fallon

Corey Fallon is a cognitive scientist specializing in human-machine teaming, with a focus on trust in technology. His research also explores risk assessment for technology integration and human vulnerabilities to cyberattacks, using both qualitative and quantitative methods.

Pacific Northwest
NATIONAL LABORATORY

Thank you