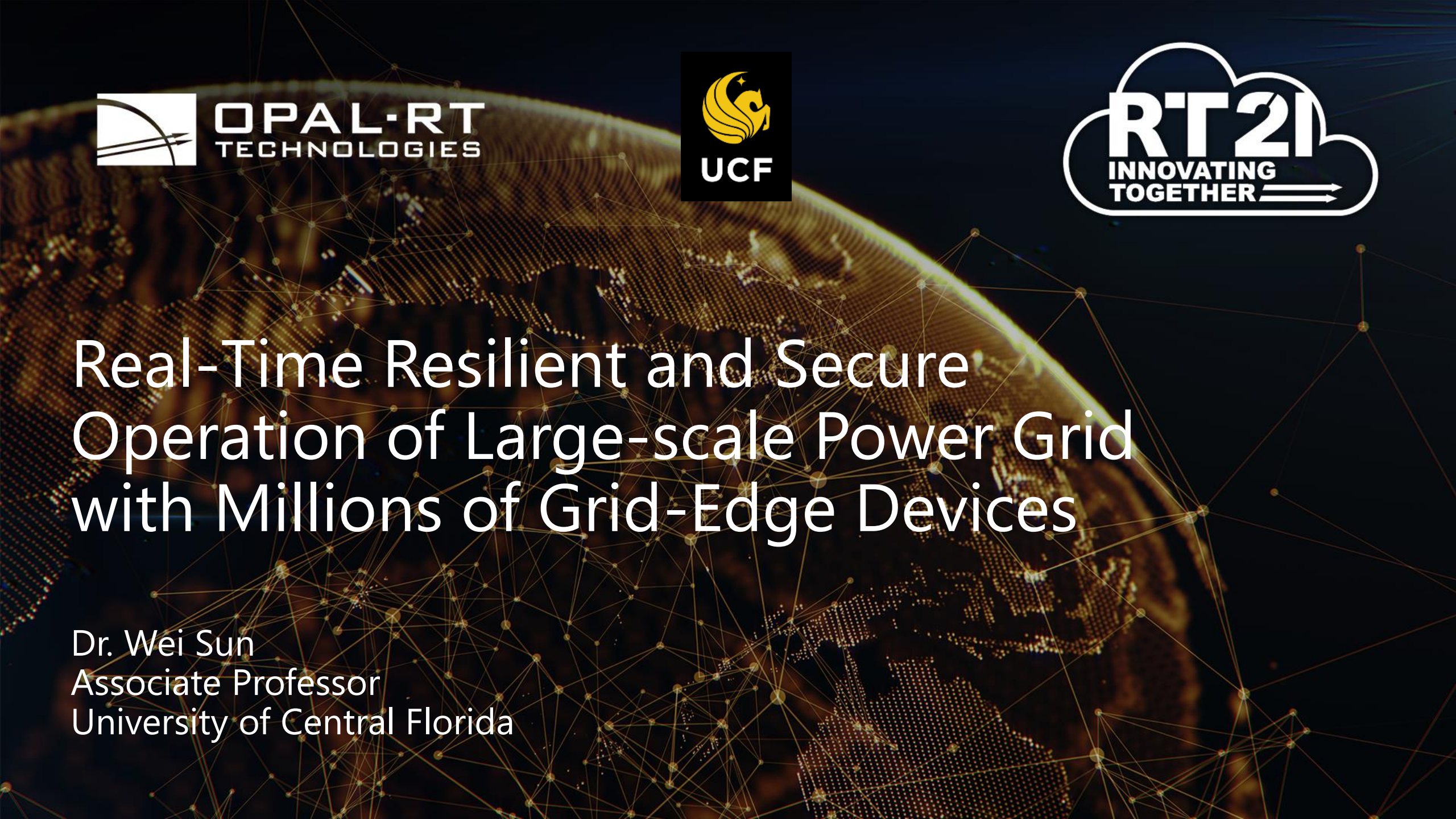

Real-Time Resilient and Secure Operation of Large-scale Power Grid with Millions of Grid-Edge Devices

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ABOUT MYSELF

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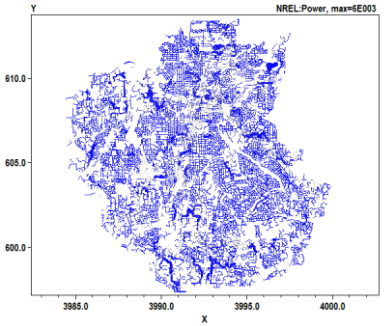
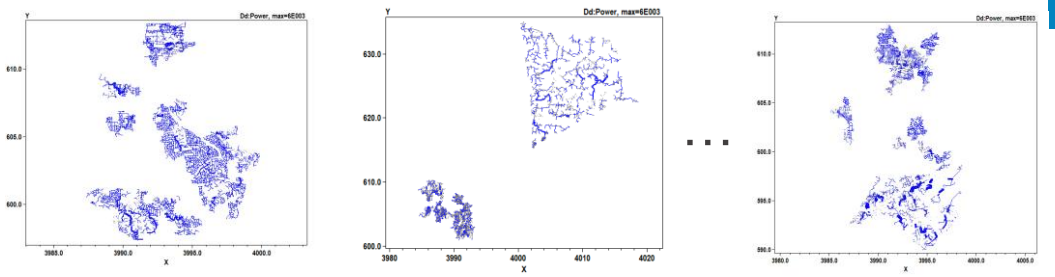
- **Research Interests**
  - **Resilience** (power system restoration, self-healing smart grid)
  - **Security** (cyber-physical system security, critical infrastructure)
  - **Renewable** (grid integration, distributed energy resources, microgrid, data centers)
- **Research Projects**
  - **PI**: Cyber-physical security (DOE), Intelligent Restoration (NSF), DER modeling in T&D systems (EPRI), Cybersecurity (Cyber Florida) ~$5M
  - **Co-PI**: SolarExPert (DOE), Inverter control (DOE), Energy storage (Duke Energy), Smart building and grid (DOE), FEEDER Center (DOE) ~$16M
- **IEEE Power & Energy Society**
  - **Co-chair** of Working Group on Power System Restoration
  - **Co-chair** of Task Force on Power System Restoration with Renewable Energy Sources

Scalable/Secure Cooperative Algorithms and Framework for Extremely-high Penetration Solar Integration (SolarExPert)

(UCF, NREL, HNEI, Duke, Siemens, OPAL-RT)

1 Million Node System

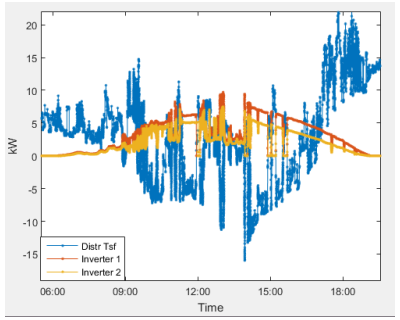




NREL Synthetic Networks:
Bay Area (7M) + Greensboro, NC (3M)

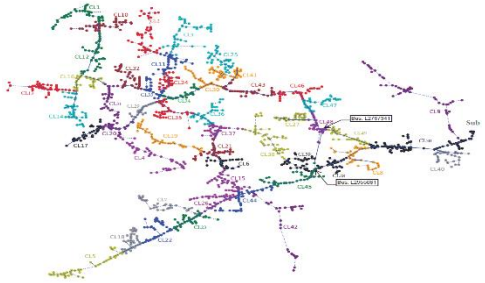
Ten 100k-node systems
(urban/suburban, industrial, rural)

100% PV Penetration

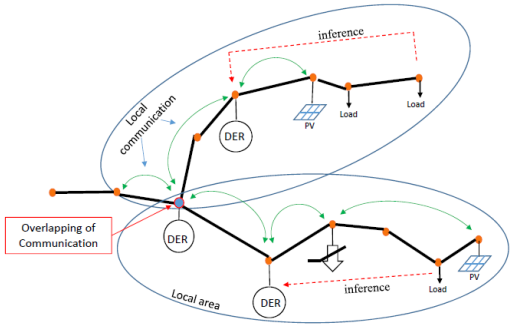


Actual System Data (Duke, Hawaii) + Different PV sizes and location (Large, Small) + Worst-Case Scenarios (OVSI)

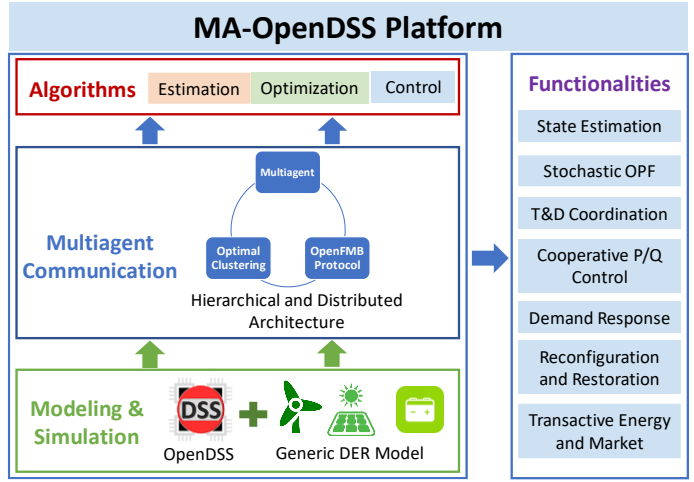
Real-Time Control and Operation



Autonomous Clustering



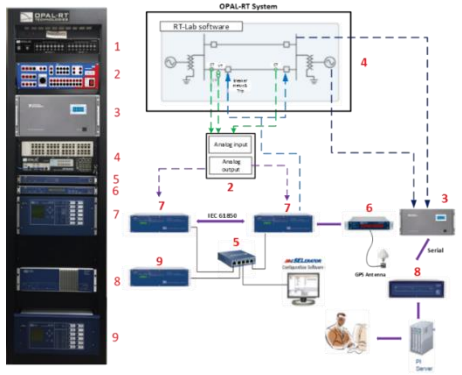
Distributed Control and Optimization



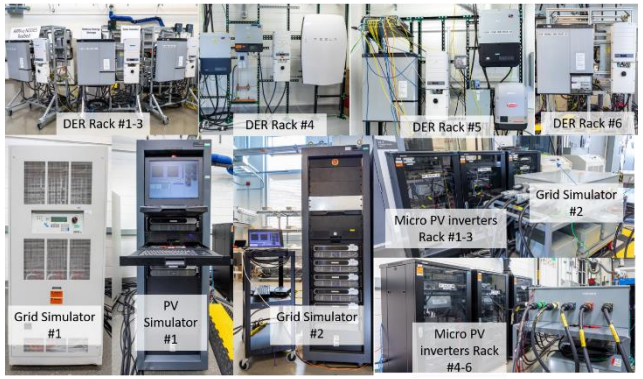
Scalable/Secure Cooperative Algorithms and Framework for Extremely-high Penetration Solar Integration (SolarExPert)

(UCF, NREL, HNEI, Duke, Siemens, OPAL-RT)

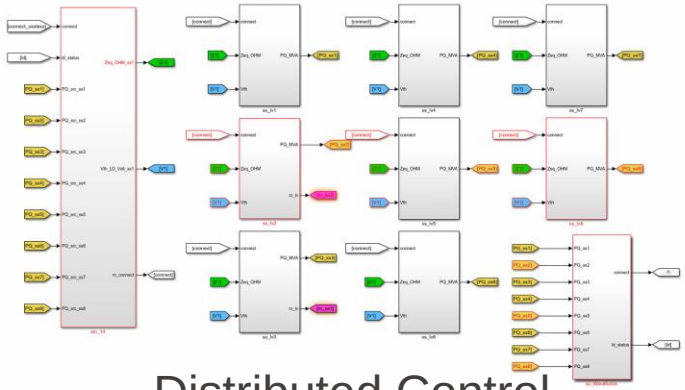
HIL Real-Time Simulation



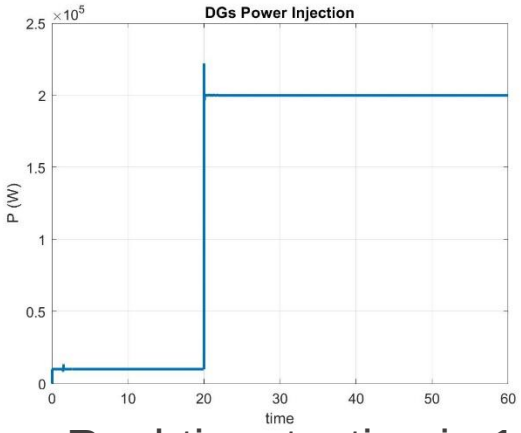
OPAL-RT Testbed at UCF

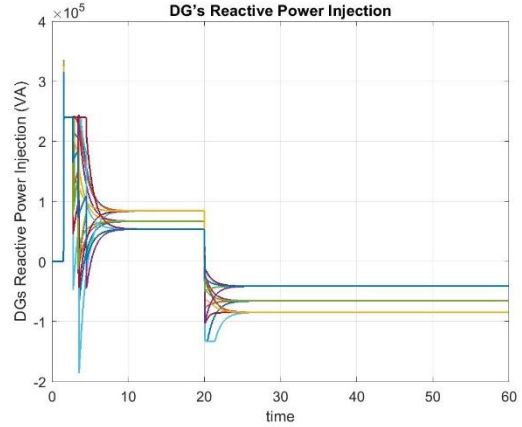


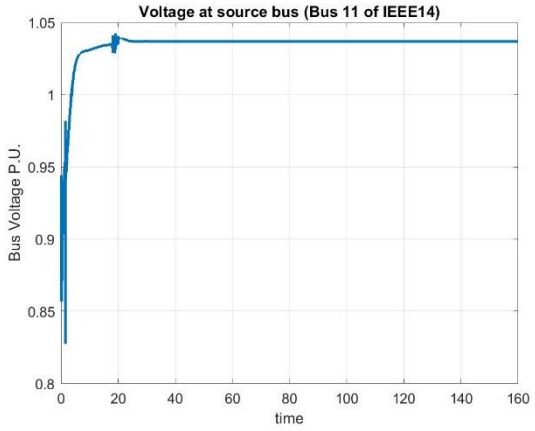
Controller-HIL and Power-HIL at NREL

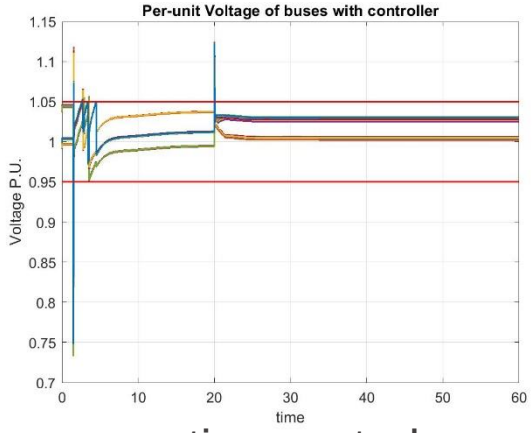


Distributed Control Implementation in OAPL-RT









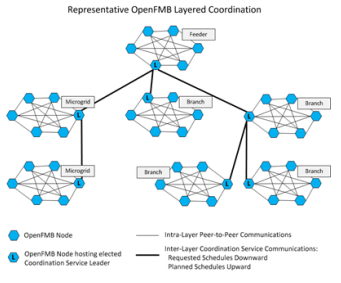
- Real-time testing in 100,000-node T&D system, including 15 controls with distributed cooperative control
- Initial power injection at 10kW, second power injection at 200kW at 20 seconds

DOE SETO CYBERSECURITY PROJECT

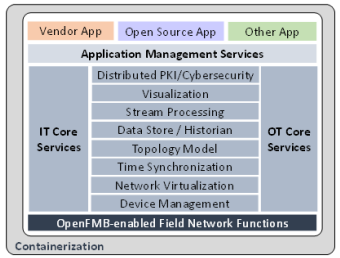
Secure and Resilient Operations Using Open-Source Distributed Systems Platform (OpenDSP)

(UCF, VT, OES, Duke, Consumers)

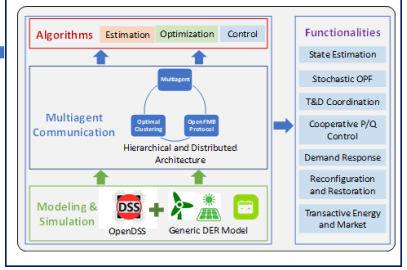
OpenFMB Interoperability Framework



OpenDSP Solution Architecture



Multi-agent Cooperative Control and Distributed Optimization



Distributed Intelligence

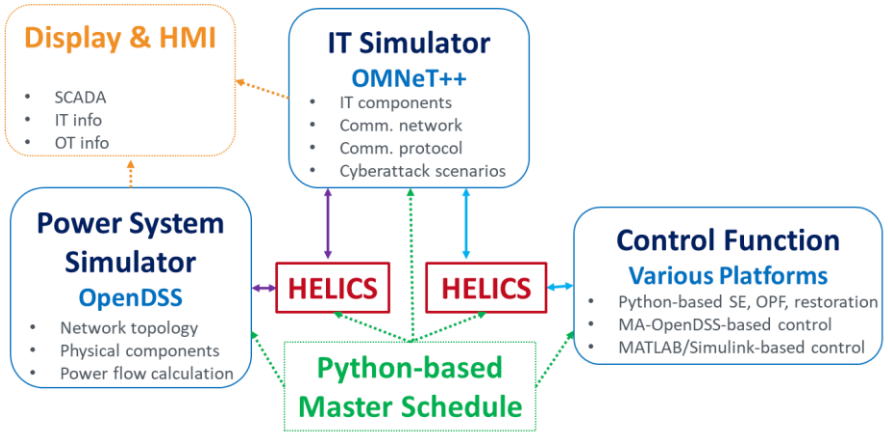
Multichannel Solutions

Data-driven and Learning-enabled Schemes

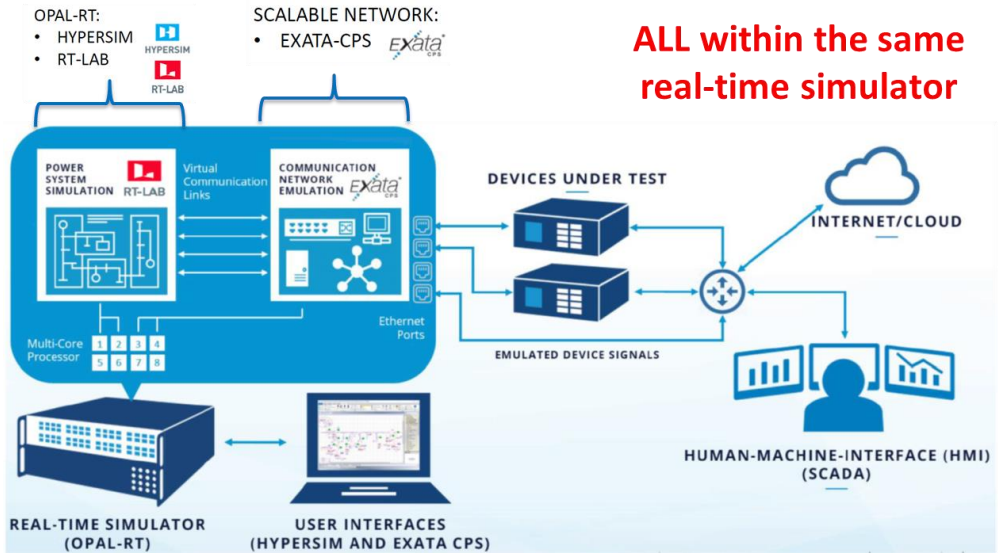
Uncertainty in Decision-Making

Adaptive Self-Healing + **Proactive Defense**

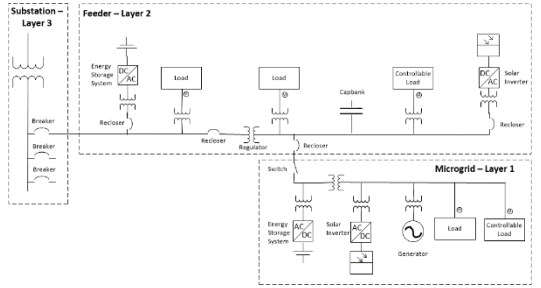
- Layer 6 – Endure by Coordinated System Operation
- Layer 5 – Recover through Adaptive Reconfiguration
- Layer 4 – Respond by Attack-Resilient Cooperative Control
- Layer 3 – Detect Intrusions and Data Robustification
- Layer 2 – Protect the IT/OT Infrastructure
- Layer 1 – Identify Vulnerability and Assess Threats

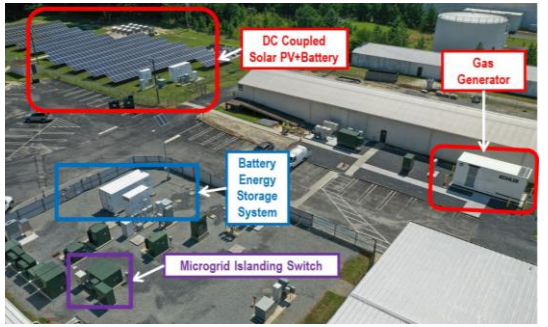


Open-Source CPS Security Testbed



Real-Time Cyber-Physical Simulator





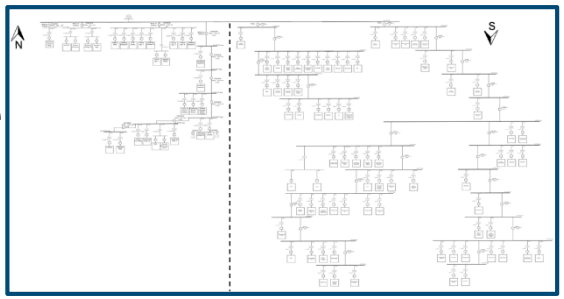
Duke Mt Holly Microgrid Test Facility

SIEMENS
UCF CAMPUS MICROGRID

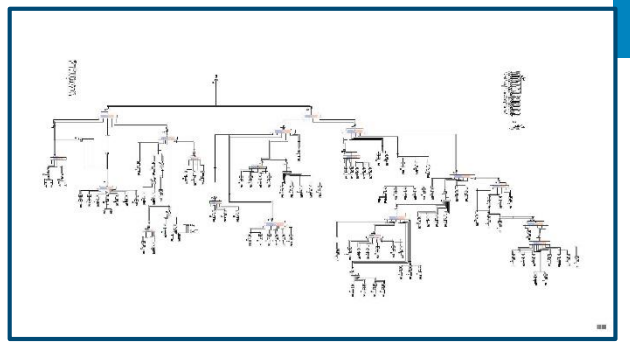
UCF Siemens Digital Grid Lab



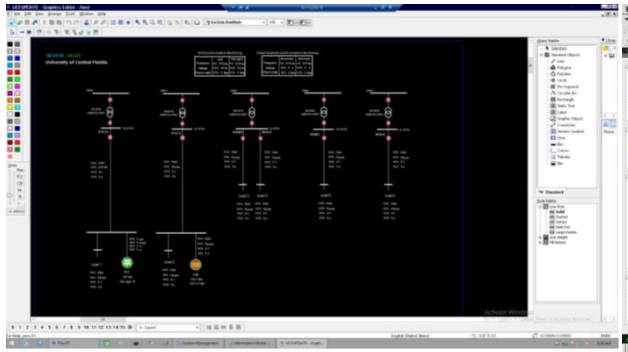
One-Line Diagram

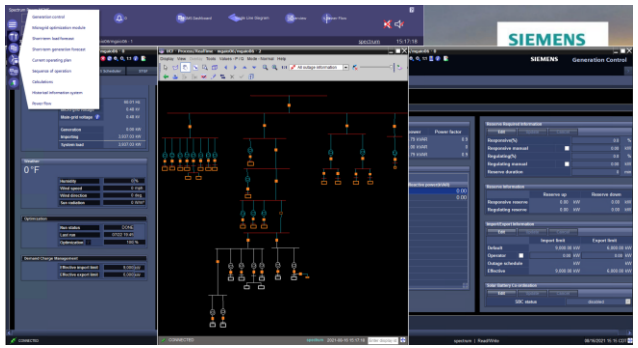


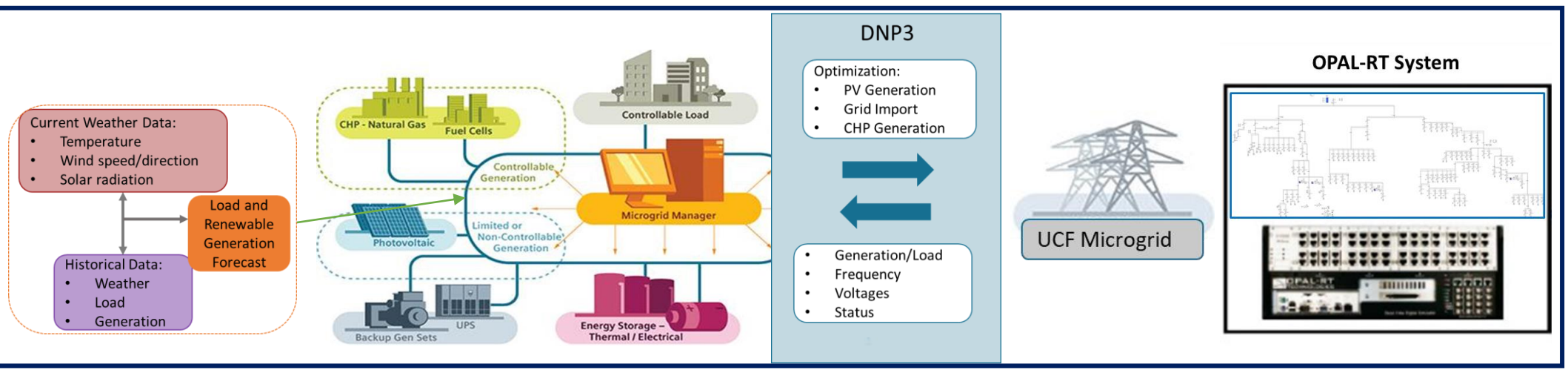
Model in OPAL-RT



Model in Siemens Microgrid Management System (MGMS)







RT21 INNOVATING TOGETHER