SAND2019-10562C

Global RT SuperLab Team Introduction

September 26, 2017

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Global RT-SuperLab Team

REAL-TIME SUPER LAB

Idaho National Laboratory

Colorado State University

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

WASHINGTON STATE UNIVERSITY

E.ON Energy Research Center | RWTH AACHEN UNIVERSITY

Sandia National Laboratories

UNIVERSITY OF SOUTH CAROLINA

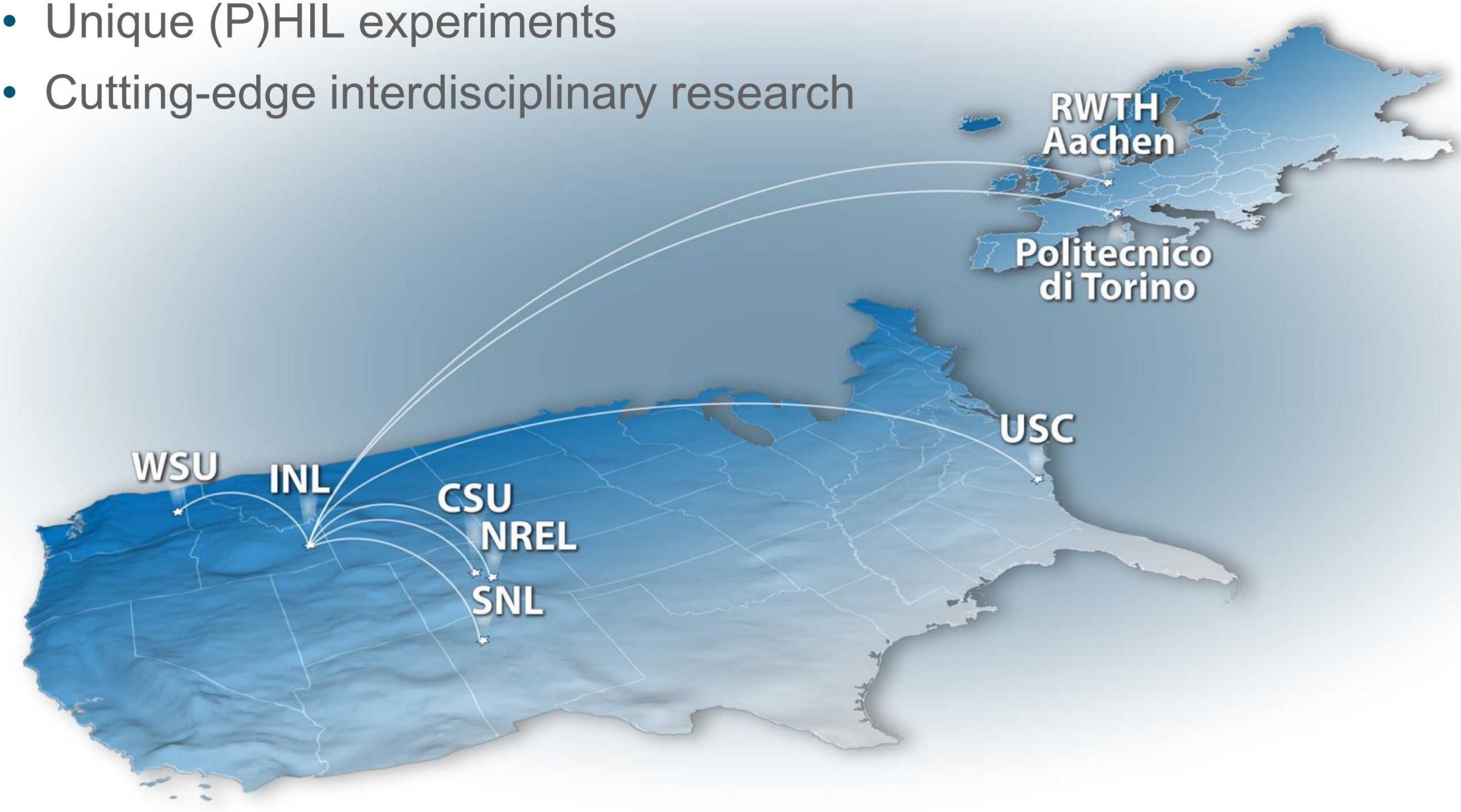
POLITECNICO DI TORINO

G-RTSLab

Super Lab for the Futuristic Grids

Collaborative research infrastructure for

- Large-scale systems
- Unique (P)HIL experiments
- Cutting-edge interdisciplinary research



RT Super Lab & Next-Gen Global Grids

- Collaboration between USA and EU institutions enables research groups to jointly investigate innovative solutions such as a direct submarine HVDC cable between USA and EU within the concept of Global Power Grid
- RT-Super Lab environment exploits complementary strengths and knowledge of USA and EU institutions that is particularly beneficial in this research context

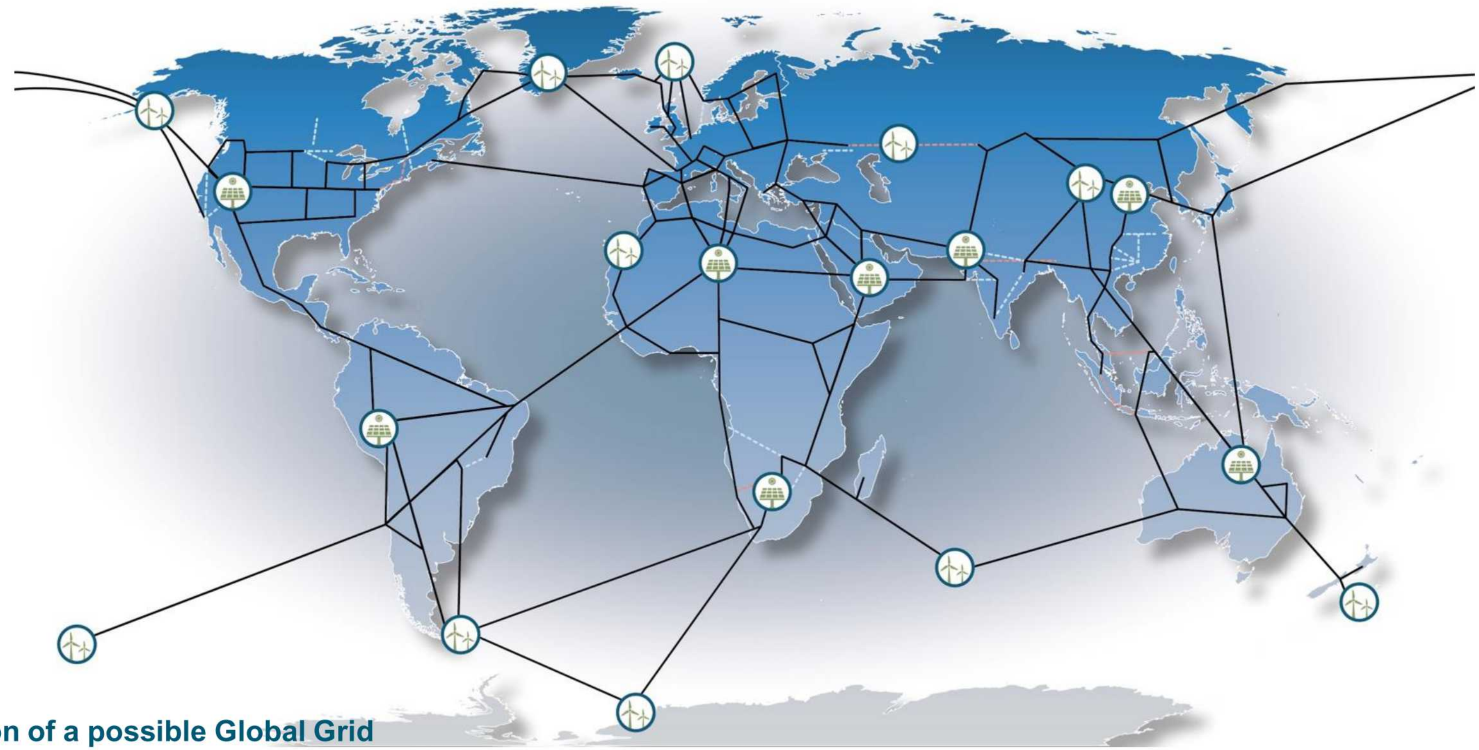


Illustration of a possible Global Grid

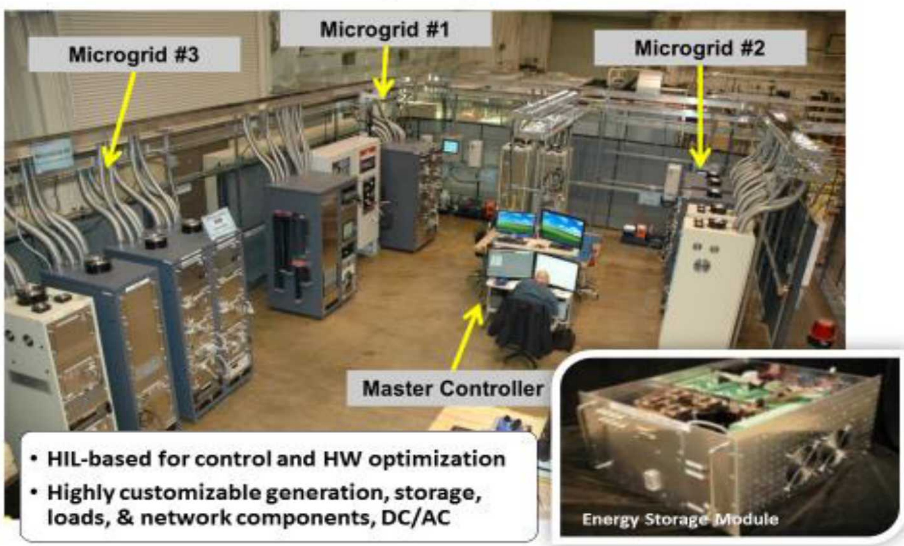
Jones, Lawrence E. *Renewable Energy Integration: Practical Management of Variability, Uncertainty and Flexibility In Power Grids.* Burlington: Academic Press, 2014.

Sandia National Laboratories (SNL)

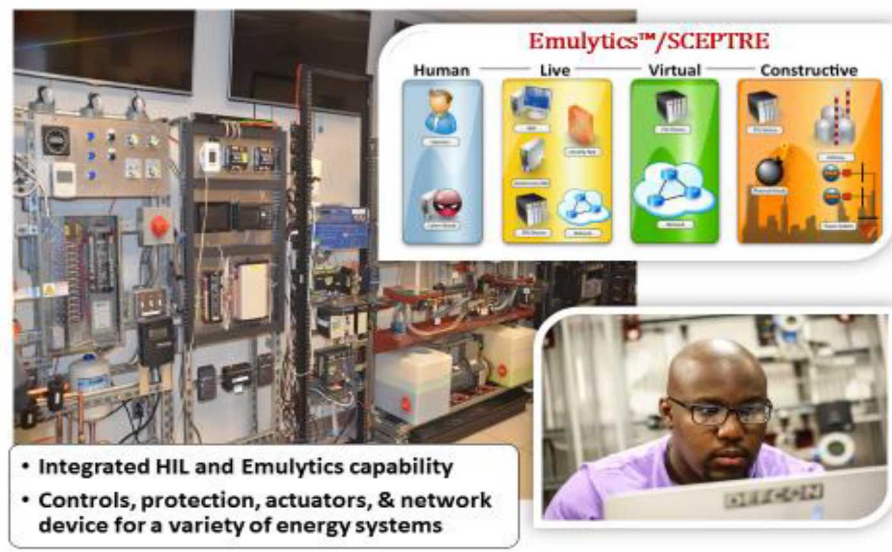
- SNL is a multi-mission DOE R&D center with headquarters in Albuquerque, New Mexico, USA.
- Conducting energy technology research, development and validation since the 1970's.
- World-class R&D platforms

Distributed Energy Resources and Energy Storage

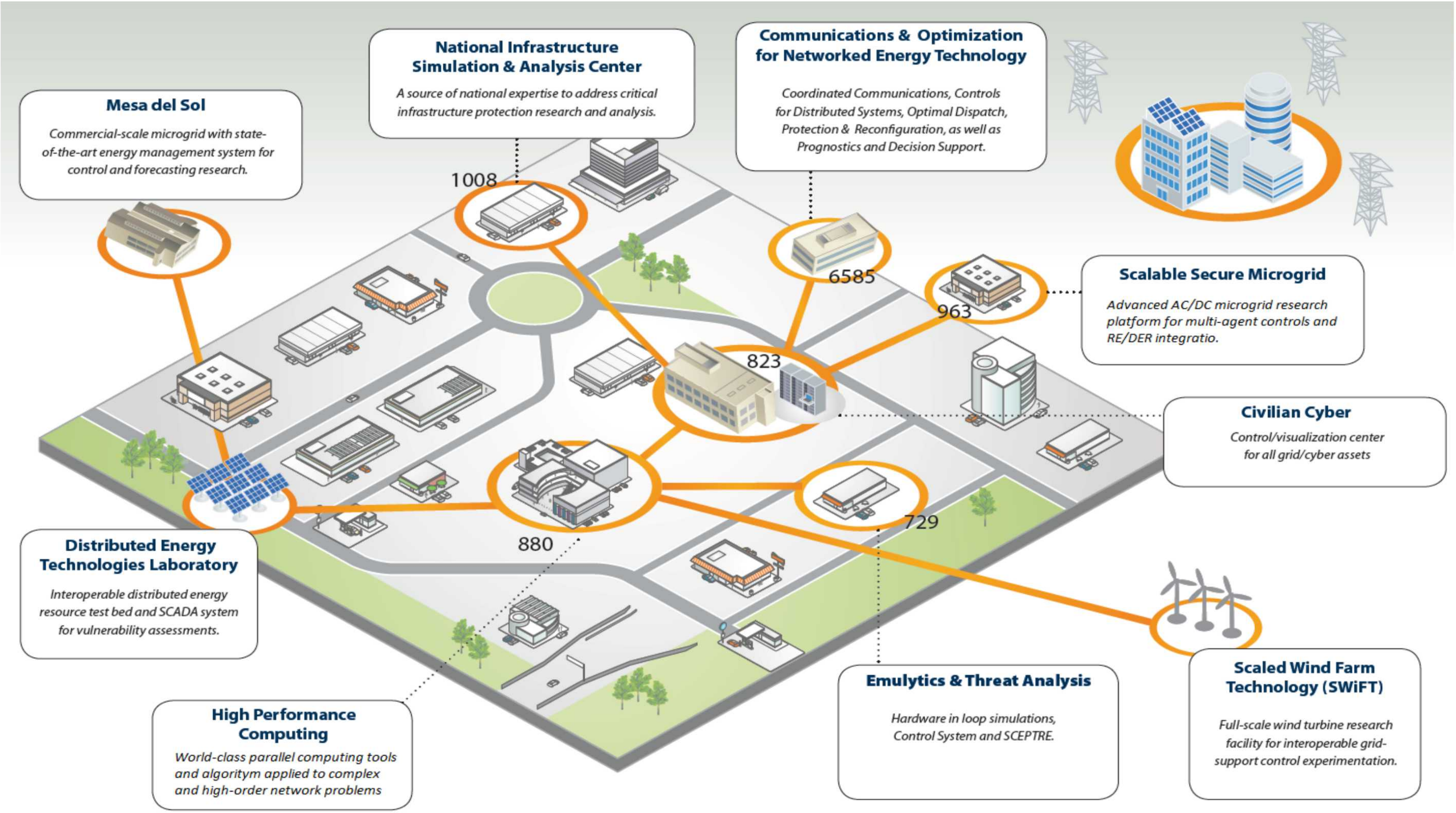
Secure Scalable Microgrid (SSM) R&D Platform



Energy/CS Cybersecurity Research Platforms



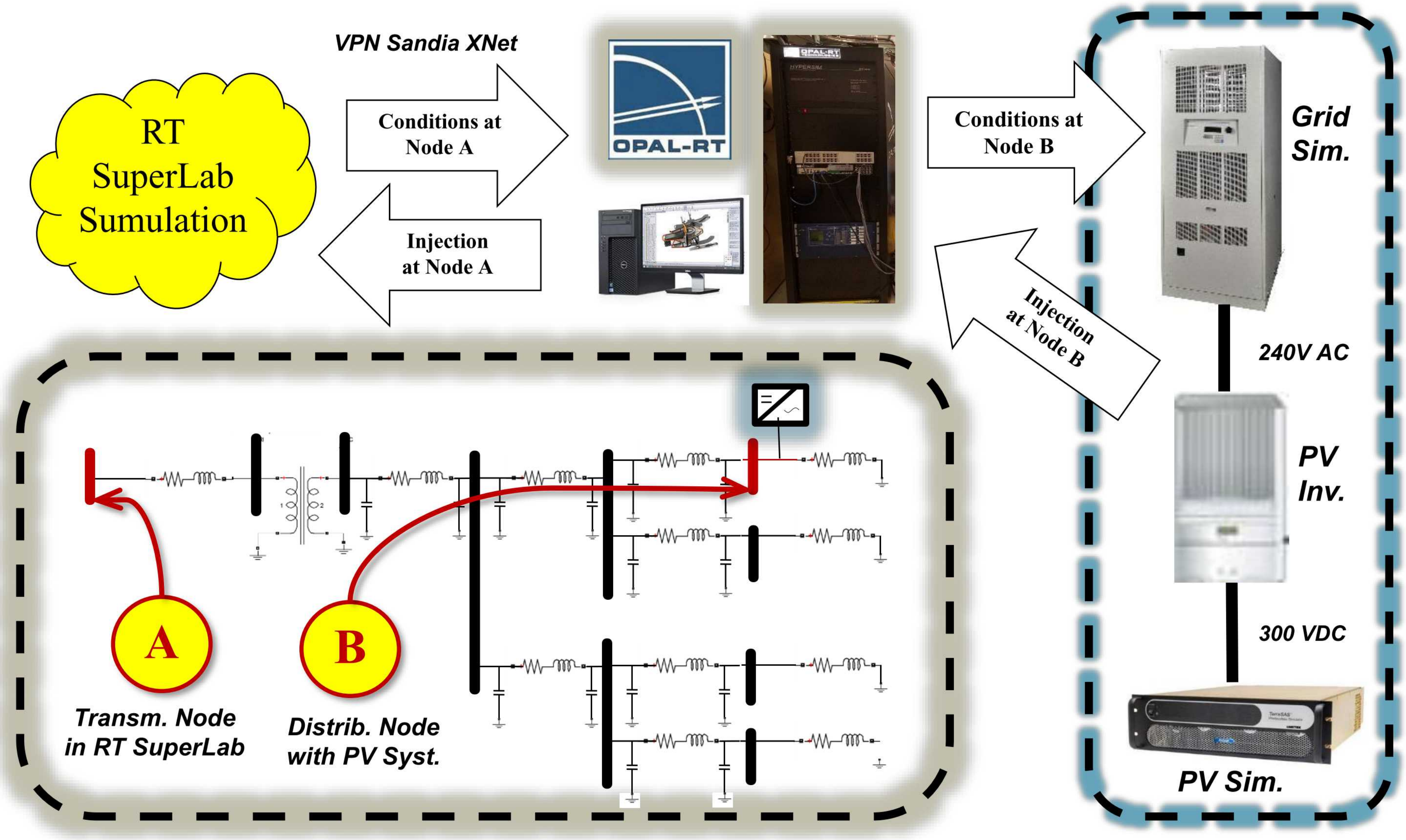
Sandia RE/DER Integration R&D Platform



- Integrated renewable and DER, cybersecurity platforms for analysis, optimization and validation of advanced energy systems
- Dedicated XNet research network, Virtual Power Plant (VPP) controls

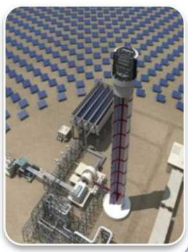
RT SuperLab Contribution – SNL

- Distribution System with high-share of PV generation (at DETL)
- Demonstrate PV supporting system stability via Q(v,t) and P(f,t)



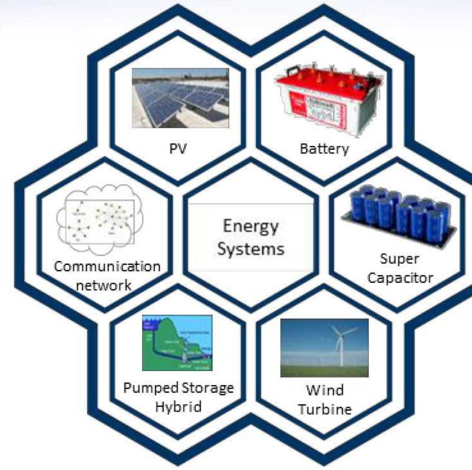
Real-time Power and Energy Laboratory – Research Principles

Research on concentrated solar power plants



Research on pumped-storage hydro for integrating multiple run-of-the-river power plants

Safe and efficient integration of grid devices to existing power grid



First Principles Research

Energy Conversion

Energy Systems Integration

- **MODELS BASED ON REAL-WORLD DATA IN REAL-TIME Physics-based Modeling**
- **Novel protection schemas and algorithms**

ENERGY CONVERSION AND STORAGE
- Thermal
- Mechanical
- Electrical
- Chemical
- Nuclear

Integration of
- Electrical Vehicles
- Supercapacitors
- Flywheels
- Pumped Storage Hydro
- Batteries and Electrolyzers To the power Grid

IMPACTS & TAKEAWAYS
- Physics model-based approach towards solving power grid problems
- Hydrogen production to enable better demand response and grid stability
- Electrical-Mechanical-Thermal-communication cosimulation capability
- Transmission, Distribution, Communication, and Communication co-simulation

INL Power & Energy Group focuses on investigating power-grid problems using real-time models, develop advanced controls and strategies to mitigate the identified problems, and de-risk integration of variety devices to the power grid.

Unifying core capabilities

Real-Time Digital Simulation of Power Systems

- Microsecond-scale resolution of grid events simulations
- Simulate transmission-distribution-communication in power systems simultaneously
- Calibrate protection hardware settings in real-time prior to field deployment.

- ***OUTCOME:*** **REAL-WORLD GRID SCENARIO ANALYSIS IN REAL-TIME**

Control Systems and Advanced Protection

- Front-end controller development
- Multi-agent protection systems and reconfiguration schemes
- Multi-agent adaptive control
- Aggregators
- PMUs
- Relays & protection devices
- Inverters

OUTCOME: **ADVANCED CONTROL SYSTEMS**

Devices and systems integration

- Fuel Cells,
- Low /high Temperature Electrolyzers
- Microgrids

OUTCOME: **ANCILLARY SERVICES**

Energy storage

- Electric Vehicles and Fuel Cell Electric Vehicles
- Pumped Storage Hydro
- Supercapacitors
- Battery

OUTCOME: **GRID STABILITY**

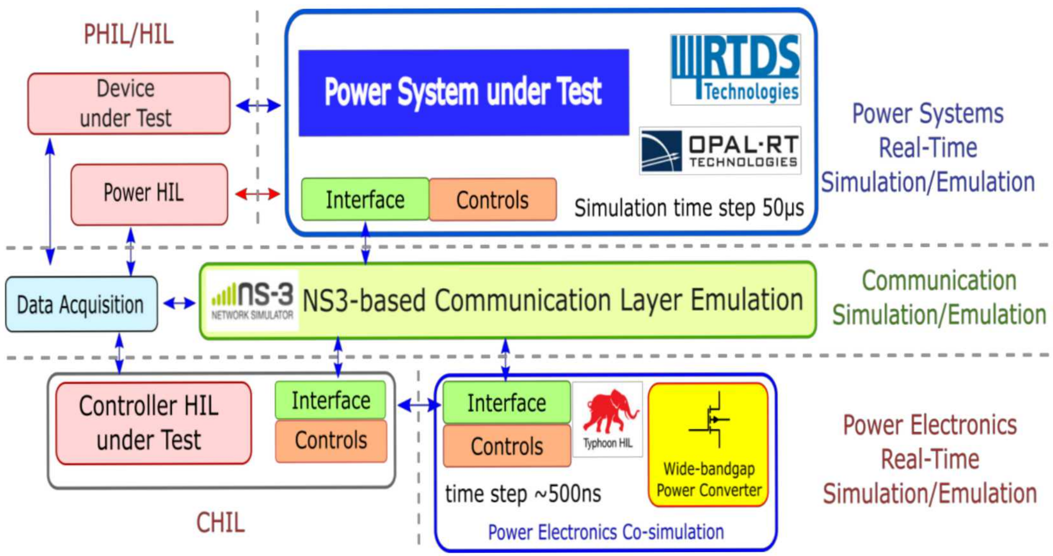
Distinguishing Capability

- Facilities for accurate real-world model development for power system dynamic analysis
- High fidelity test environment to test models based on real-world data in real-time for de-risking device integration.
- 10-20 nanosecond scale simulation for power electronic dynamics
- Control hardware in the loop and rapid prototyping of controllers.
- Advanced control technologies and decision making strategies

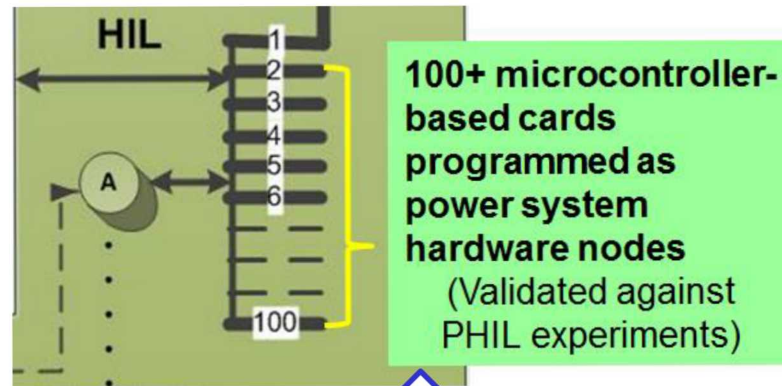
Joint Collaboration with Academia and Industry

Using unique laboratory infrastructure to create a holistic ecosystem for developing, testing and deploying power system technologies

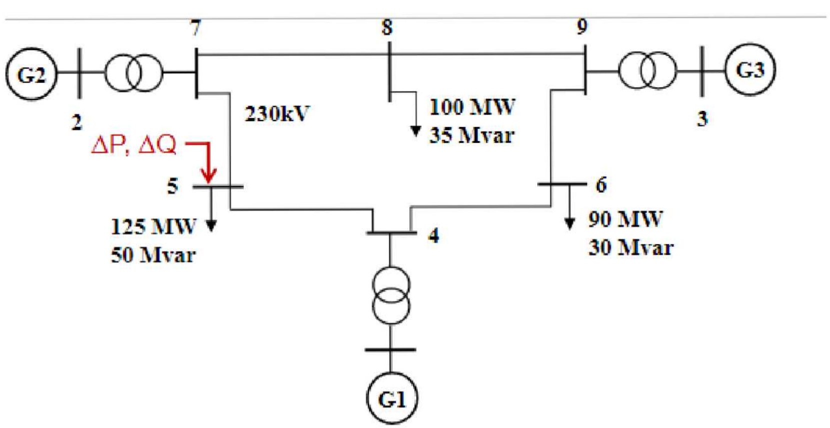
RT SuperLab Contributions - INL

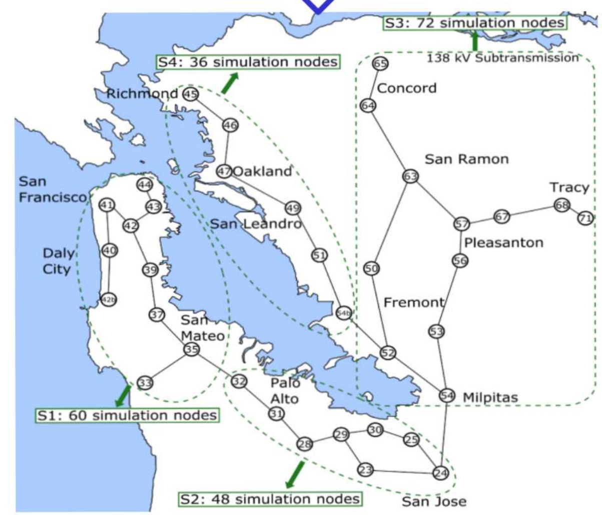


100s ARM Boards as CHIL



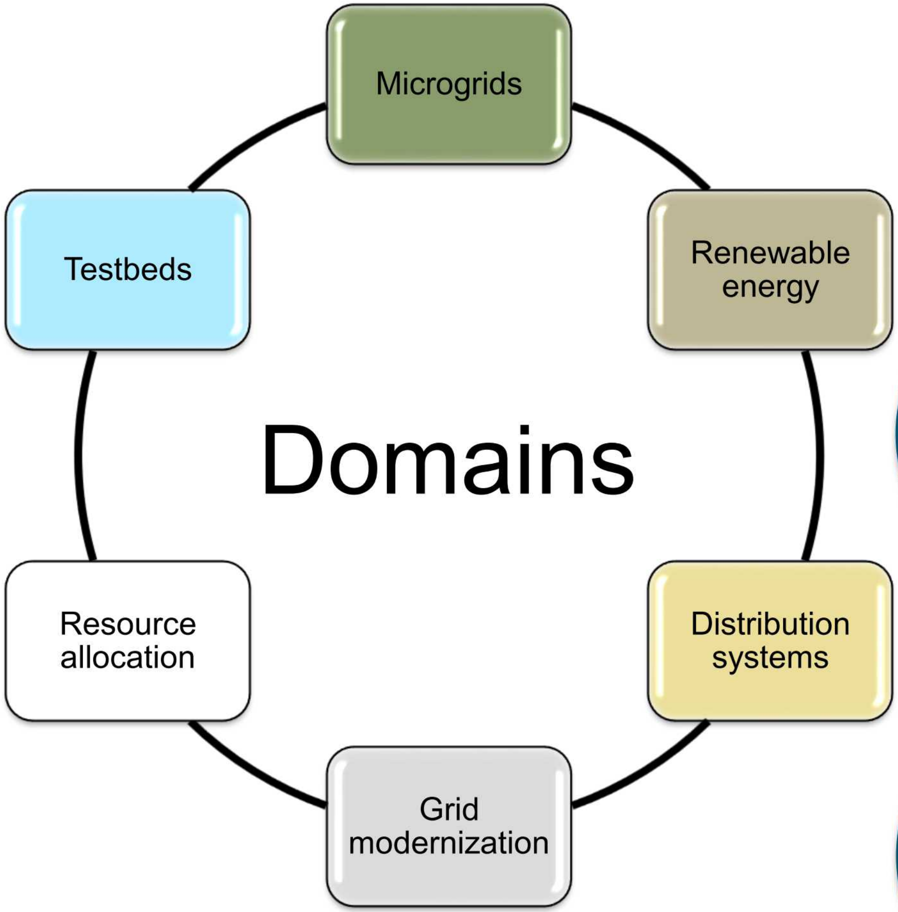
9 Bus Western Interconnection Model



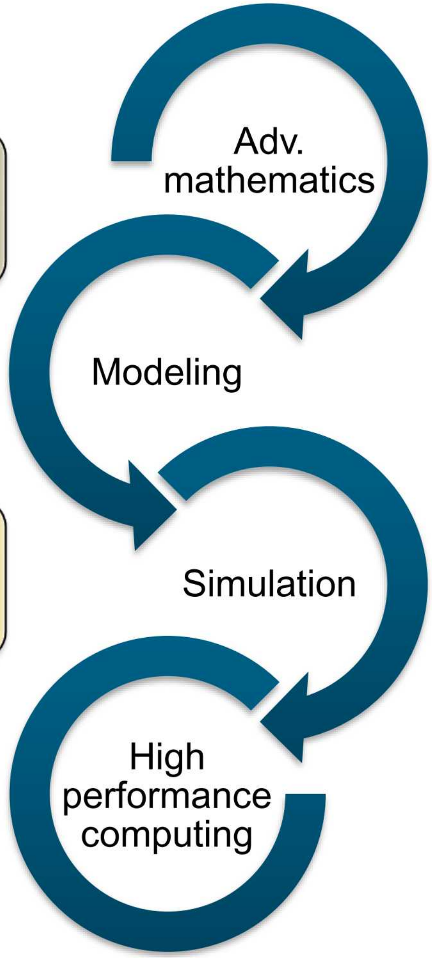


PG&E Subtransmission and Distribution Model

Advanced Power Engineering Lab (APEL)



Tools



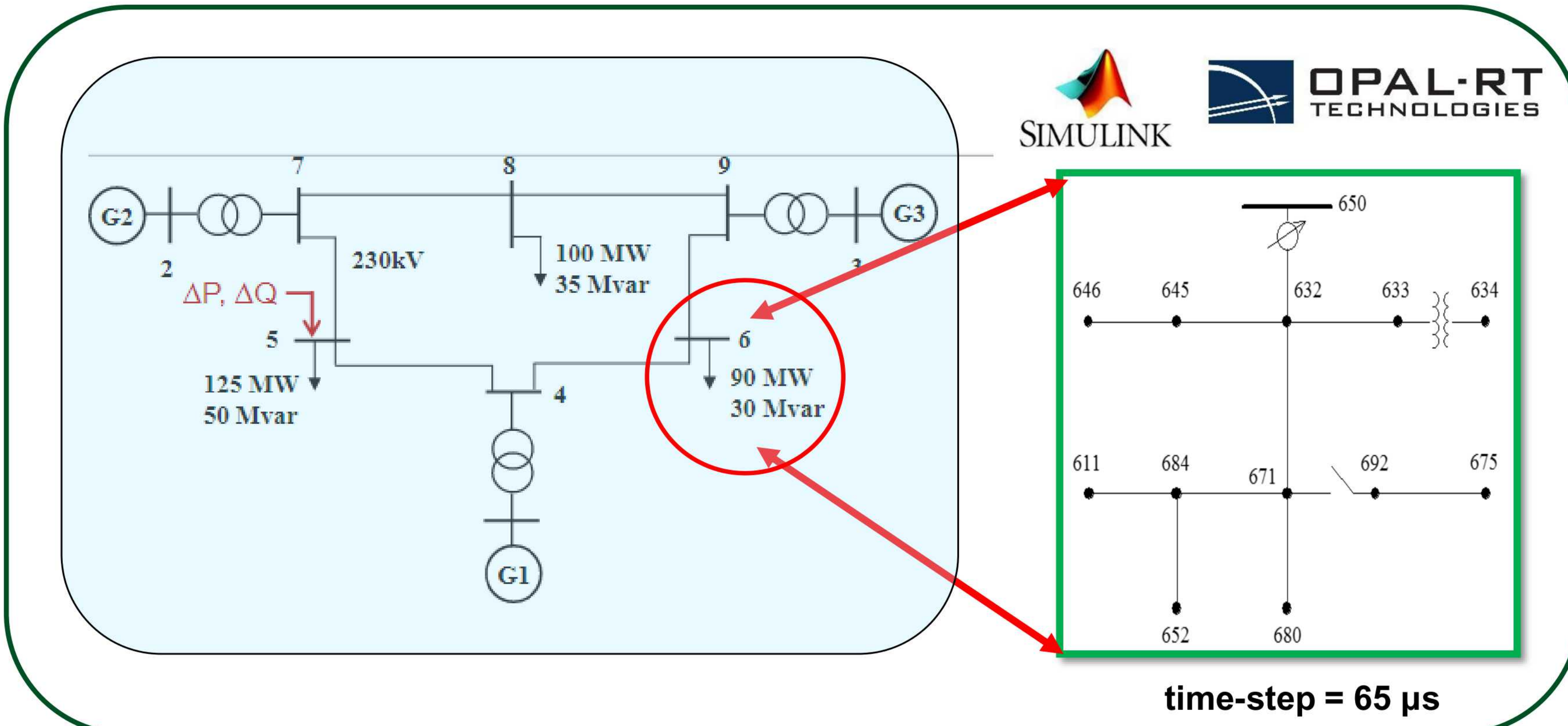
Features:

- access to power engg. software, HPC, and real time simulators
- sustained collaborations
- workforce development and education
- high impact contributions
- numerous awards

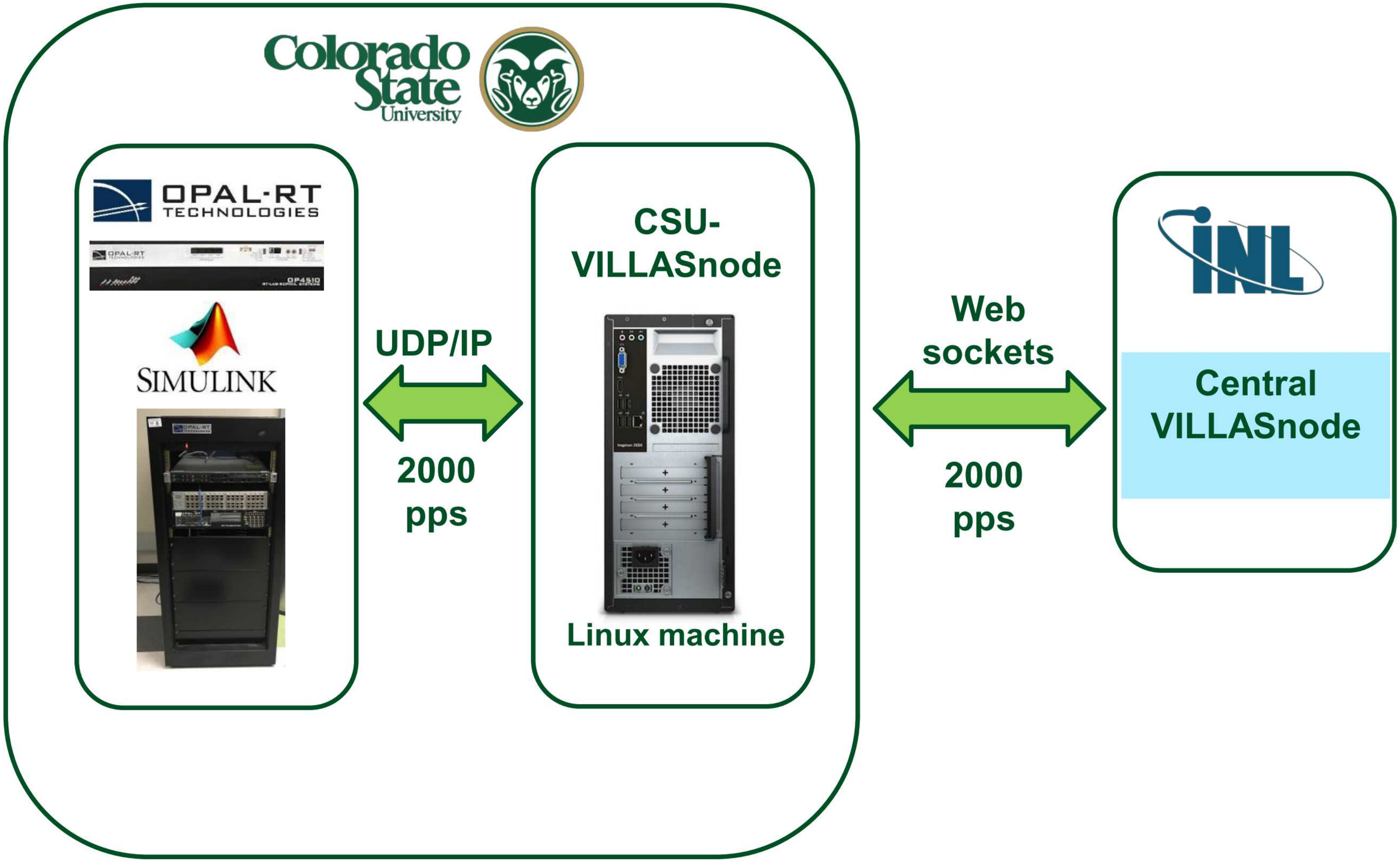
CSU's APEL is engaged in high-profile high-impact sponsored research in the area of Smart Grid and the next generation electricity infrastructure.

RT SuperLab Contributions - CSU

- created real time (RT) model of a distribution system
- integrated distribution system to the transmission system model at INL
- Quantified errors and demonstrated distributed RT simulation capabilities with INL



Distributed RT Setup between CSU and INL

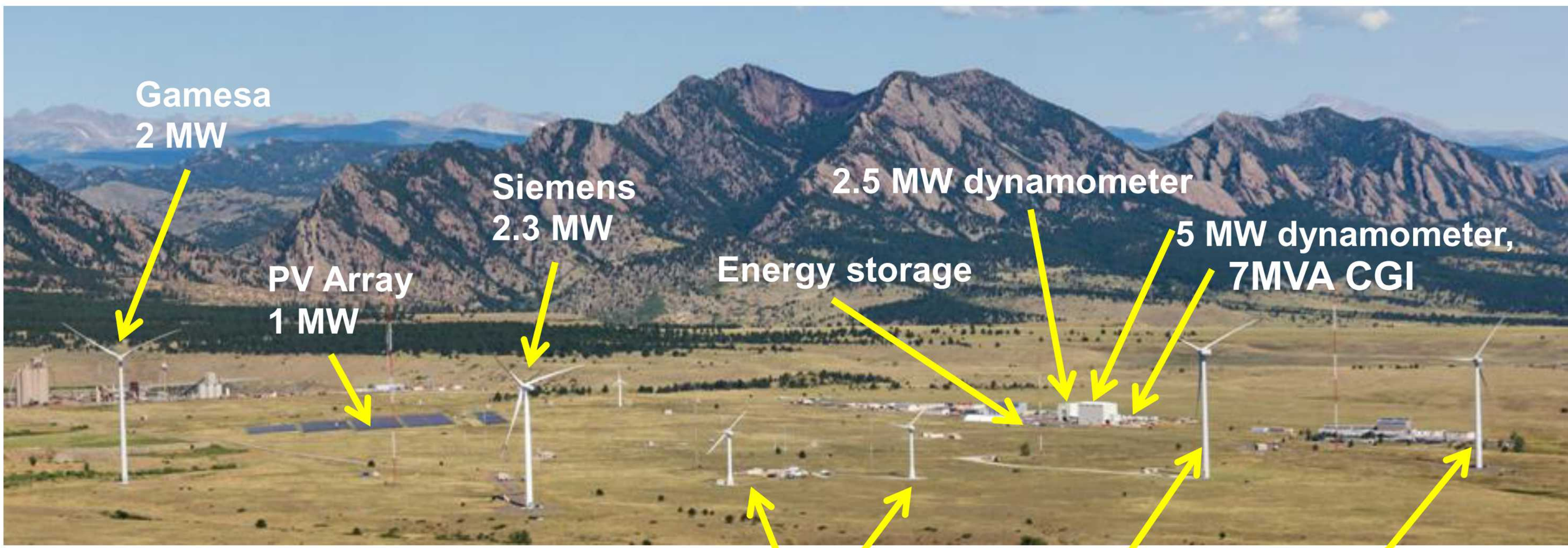


pps: packets per second

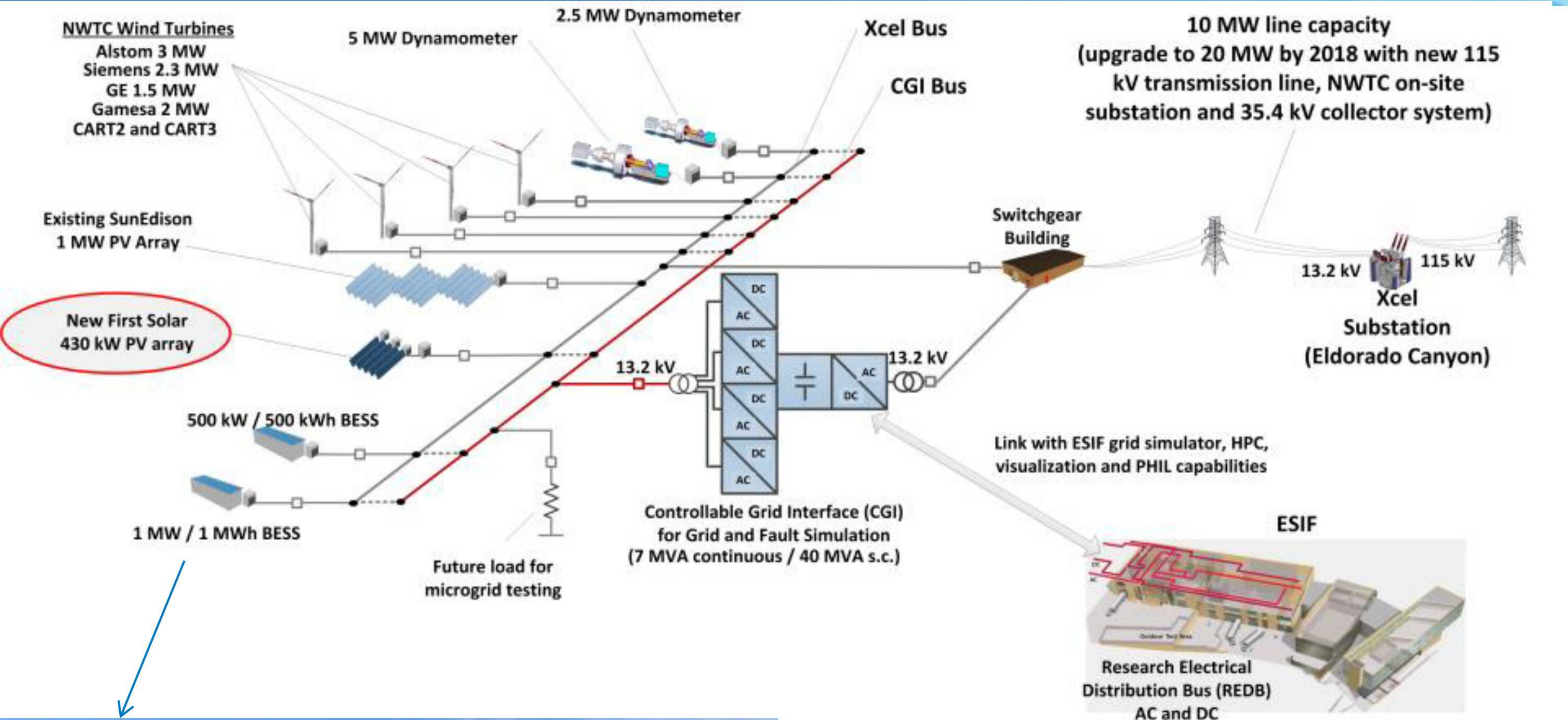
NREL's National Wind Technology Center (NWTC) Test Site

Unique Research and Validation Capabilities at a Scale that Matters

- ***Total of 11+ MW variable renewable generation currently***
- ***7 MVA Controllable Grid Interface (CGI)***
- ***Multi-MW energy storage test facility***
- ***2.5MW and 5 MW dynamometers (industrial motor drives)***
- ***Medium voltage operation***

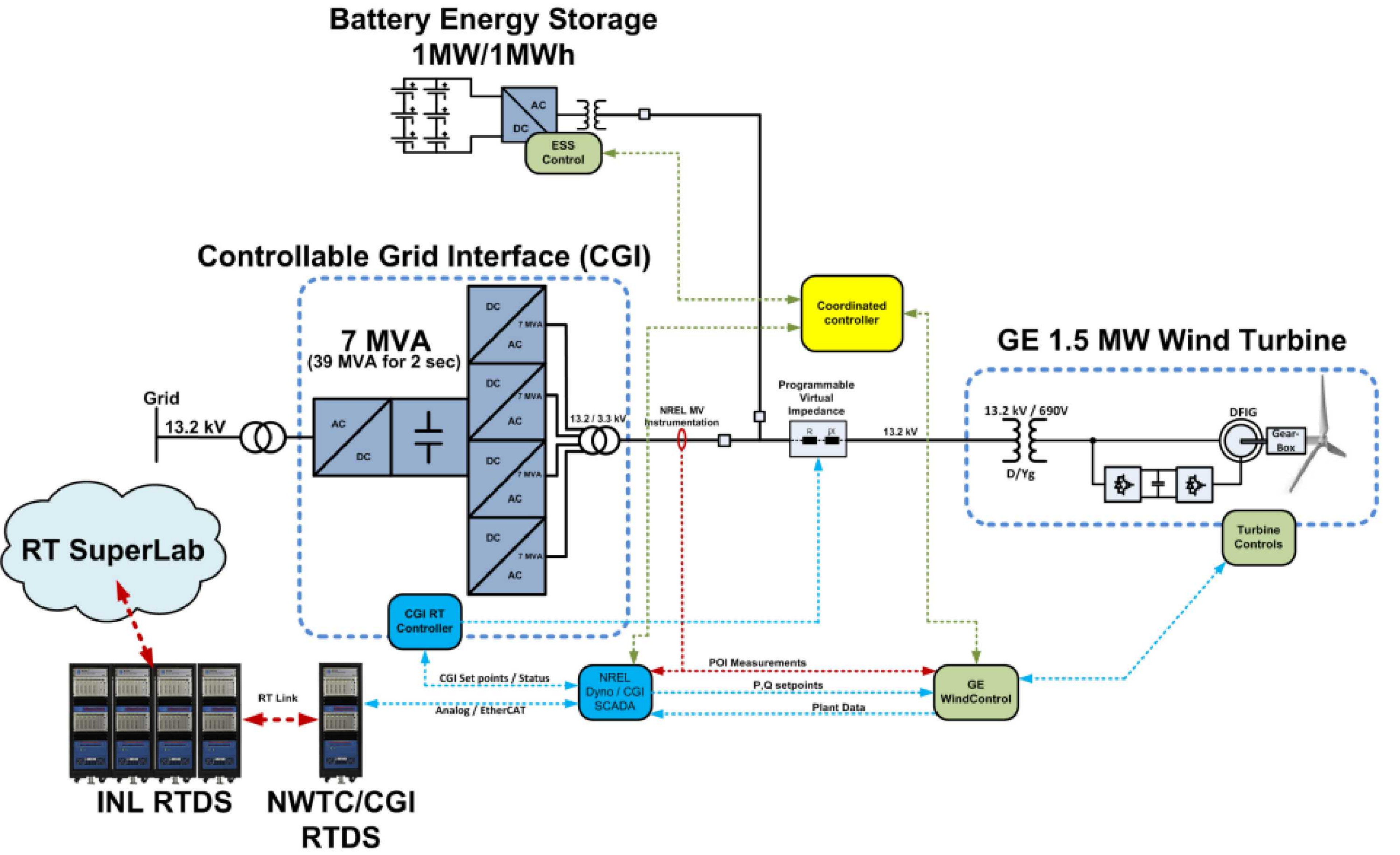


NWTC Site – Applied Energy Science "Living Lab"



Coming soon: 450 kWac PV array

NREL-INL PHIL System Integrated into RT SuperLab



InteGraL
Integrated Grids Laboratory

University of South Carolina
Energy Routing Laboratory

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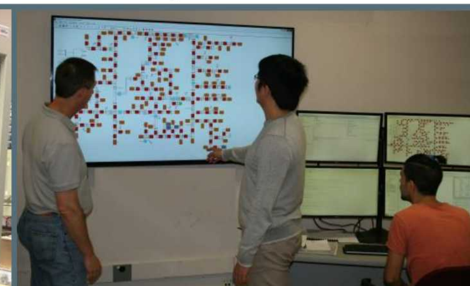
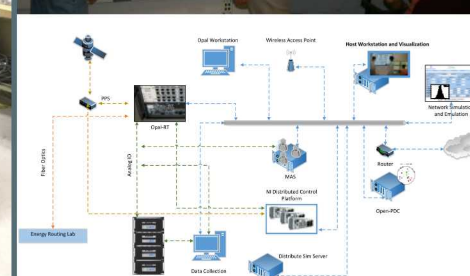
USC Micro-Grids and RT Simulation Capabilities

- Power system and communication RT simulation/emulation: Opal-RT, NS3-RT, Apposite N-91, OC-48 SONET ring
- Platforms for HIL testing of distributed monitor-control (eleven high performance CompactRIO, six multi-purpose embedded units, ten FPGA platforms)
- Linear PHIL interfaces (15kVA, up to 200kHz bandwidth) and PV emulator
- Highly reconfigurable DC/AC micro-grid (nine 75kVA converters, several motor drives and passive loads, one 60kVA MMC)

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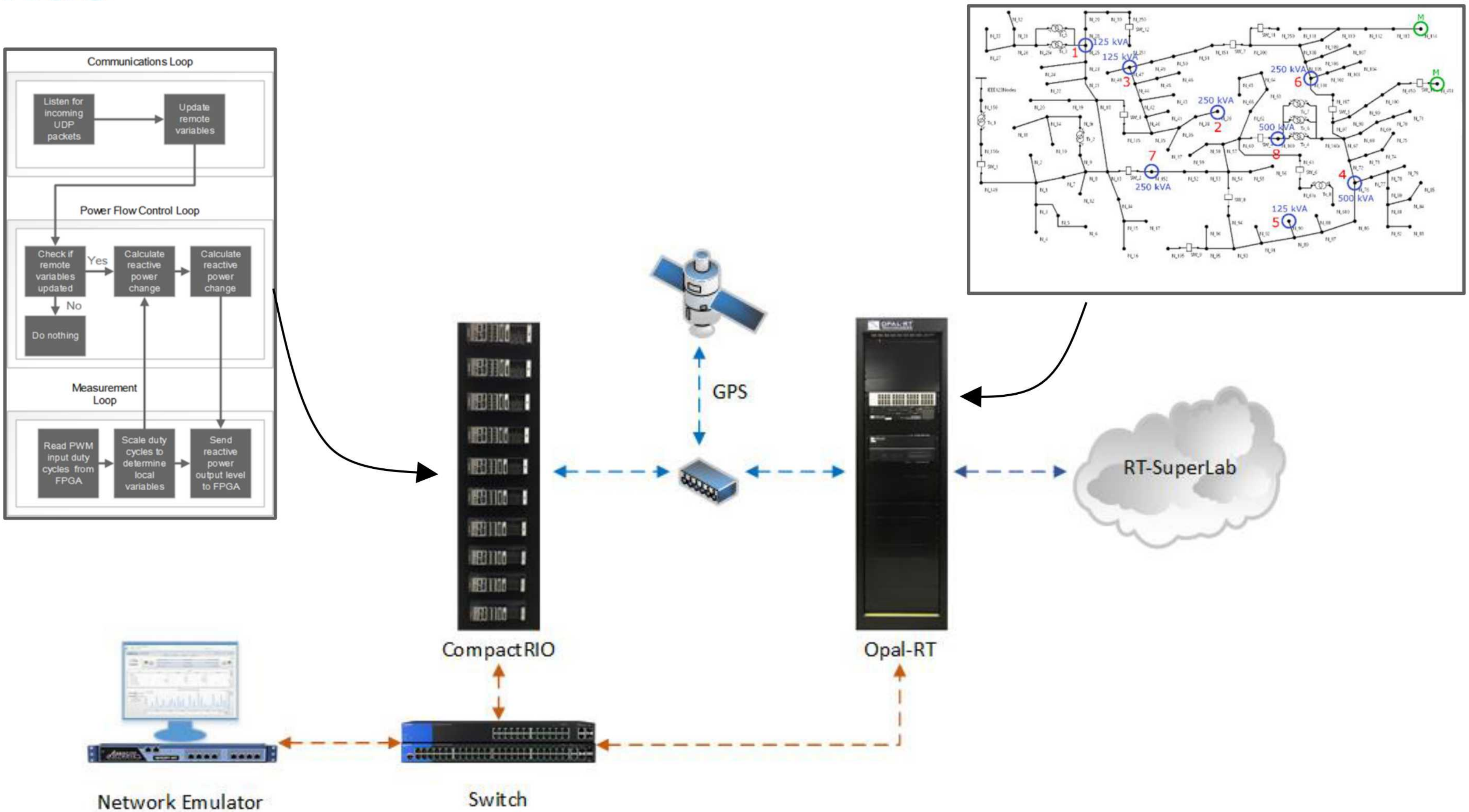
Decentralized Power Flow Control of Distribution Grids



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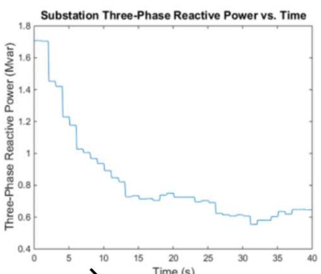
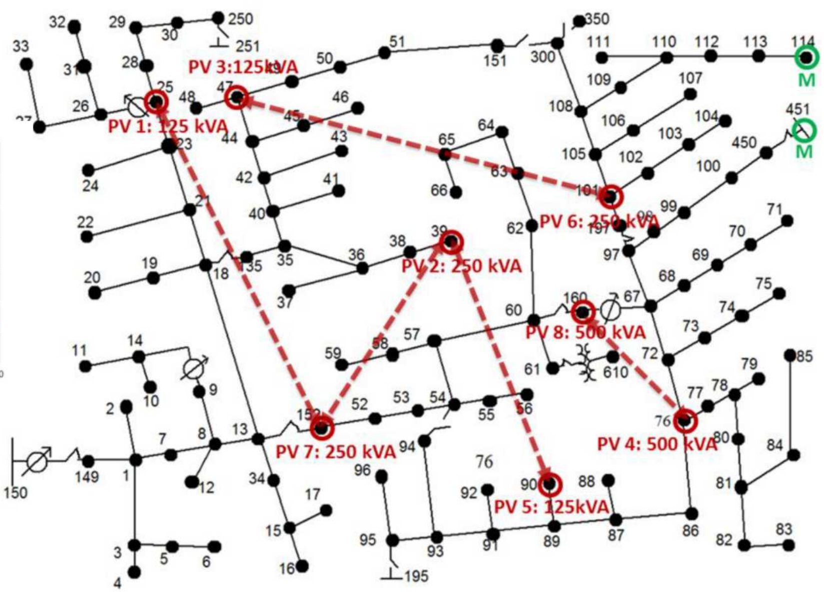
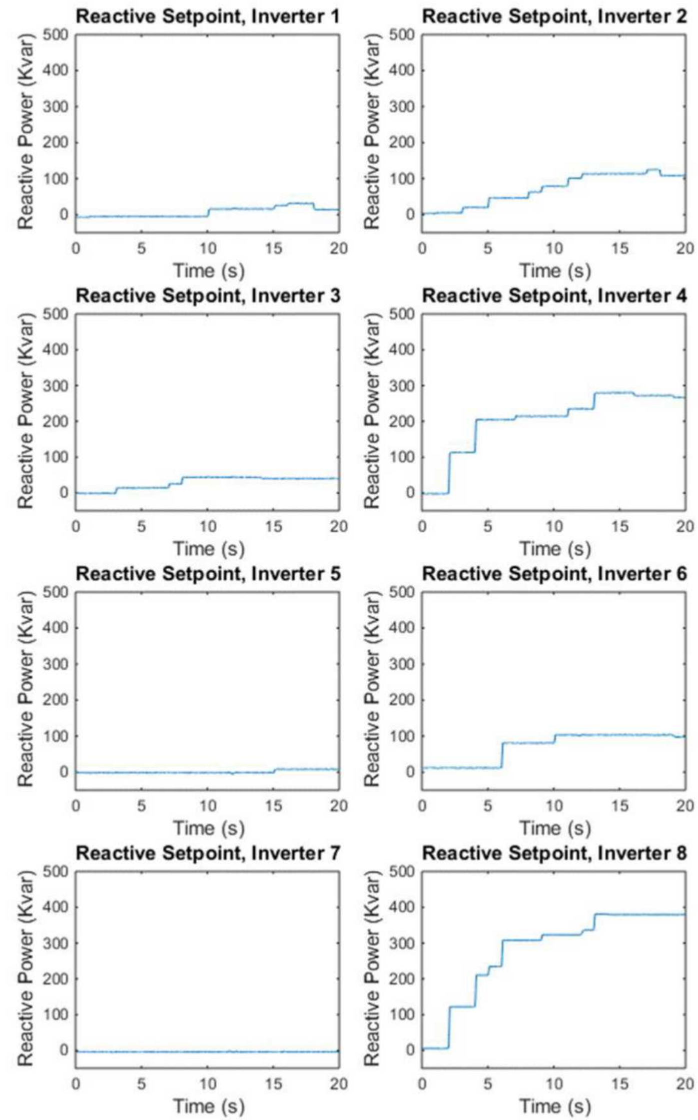






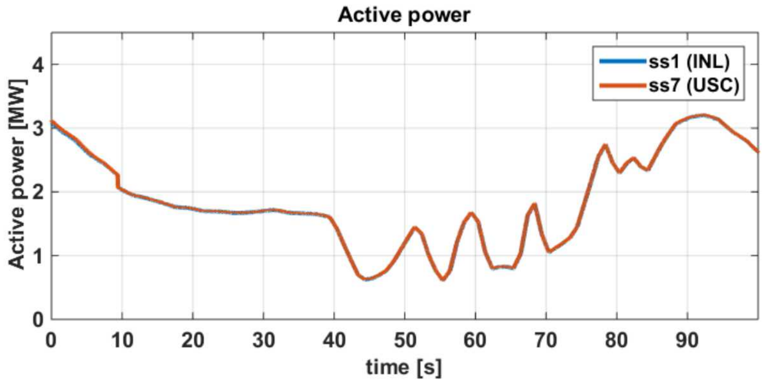
Communication Between Inverter Controllers

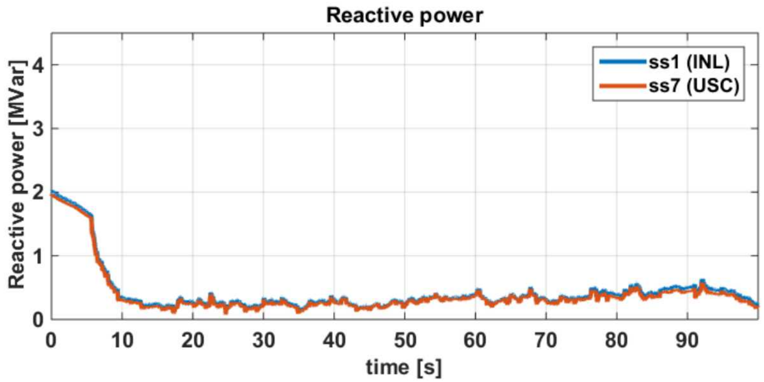
A	B	C	D	E	F
1.02	1	2	2293.8 ∠ -0.004°	2291.8 ∠ -0.043°	2.34
2.02	4	8	2213.5 ∠ -1.469°	2233.3 ∠ -1.098°	116.5
3.02	3	2	2294.2 ∠ -0.116°	2300.0 ∠ -0.038°	14.83
4.02	8	4	2253.6 ∠ -1.211°	2236.2 ∠ -1.601°	92.31
5.02	8	2	2268.5 ∠ -1.298°	2307.8 ∠ -0.048°	26.50
6.03	8	6	2271.0 ∠ -1.303°	2256.5 ∠ -1.641°	73.43
7.03	3	4	2309.2 ∠ -0.131°	2268.1 ∠ -1.796°	11.75
8.03	2	3	2317.0 ∠ -0.062°	2310.7 ∠ -0.132°	18.07
9.03	8	2	2284.6 ∠ -1.371°	2319.4 ∠ -0.072°	17.01
10.04	6	1	2273.5 ∠ -1.714°	2319.9 ∠ -0.004°	22.57
11.04	4	2	2274.4 ∠ -1.791°	2323.2 ∠ -0.076°	22.26

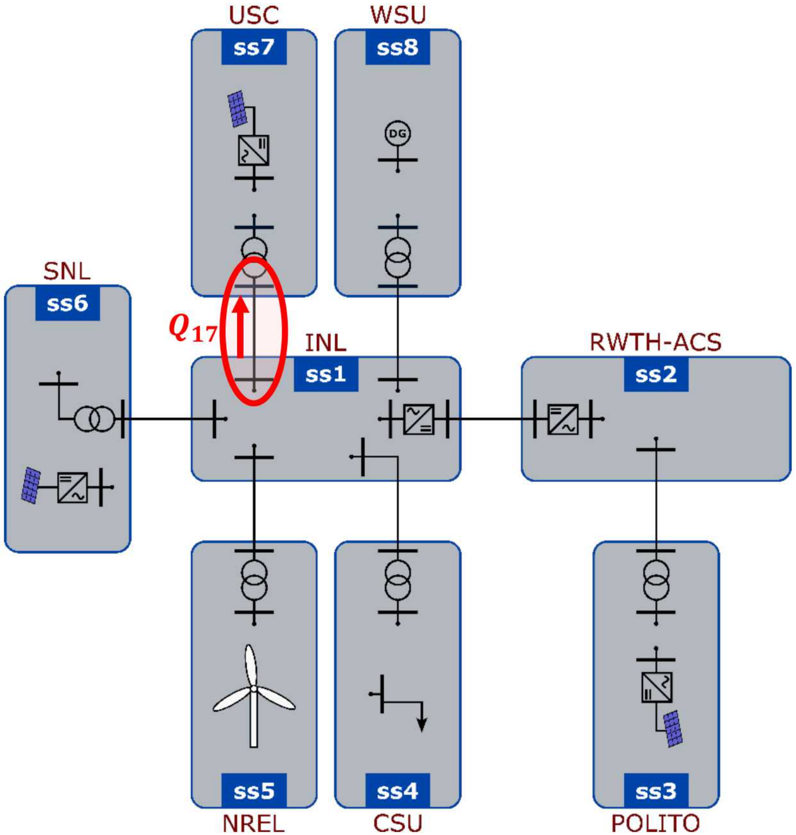
Thank You

Simulation Results - USC

- Activation of CHIL at USC (control PV inverters to minimize reactive power in IEEE 123-bus distribution system)
- Key takeaway: optimal resource utilization
- Simulation results at ss1-ss7 co-simulation interface (INL-USC)
  - Decrease in reactive power at co-simulation (substation) bus

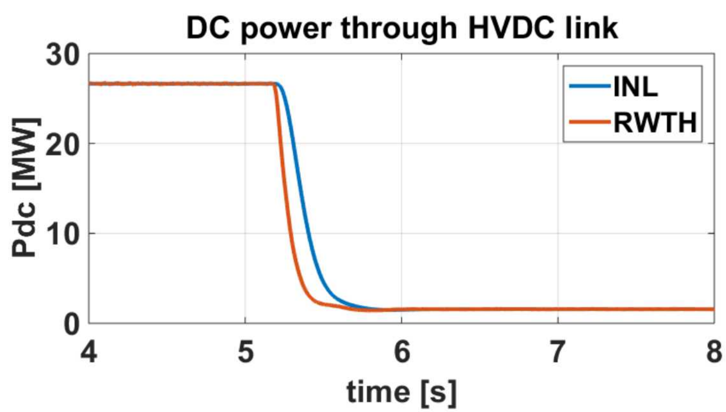


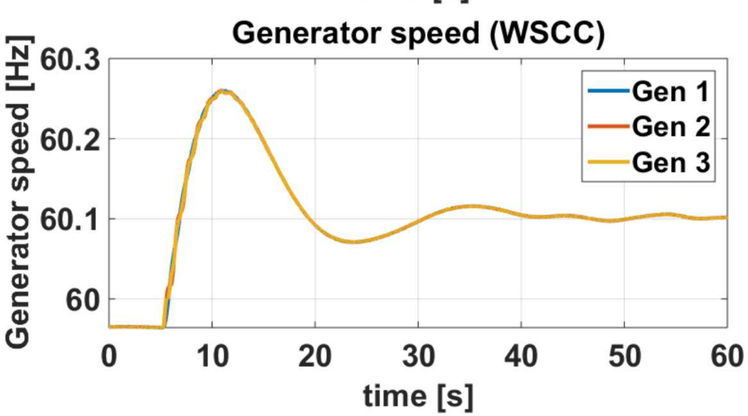


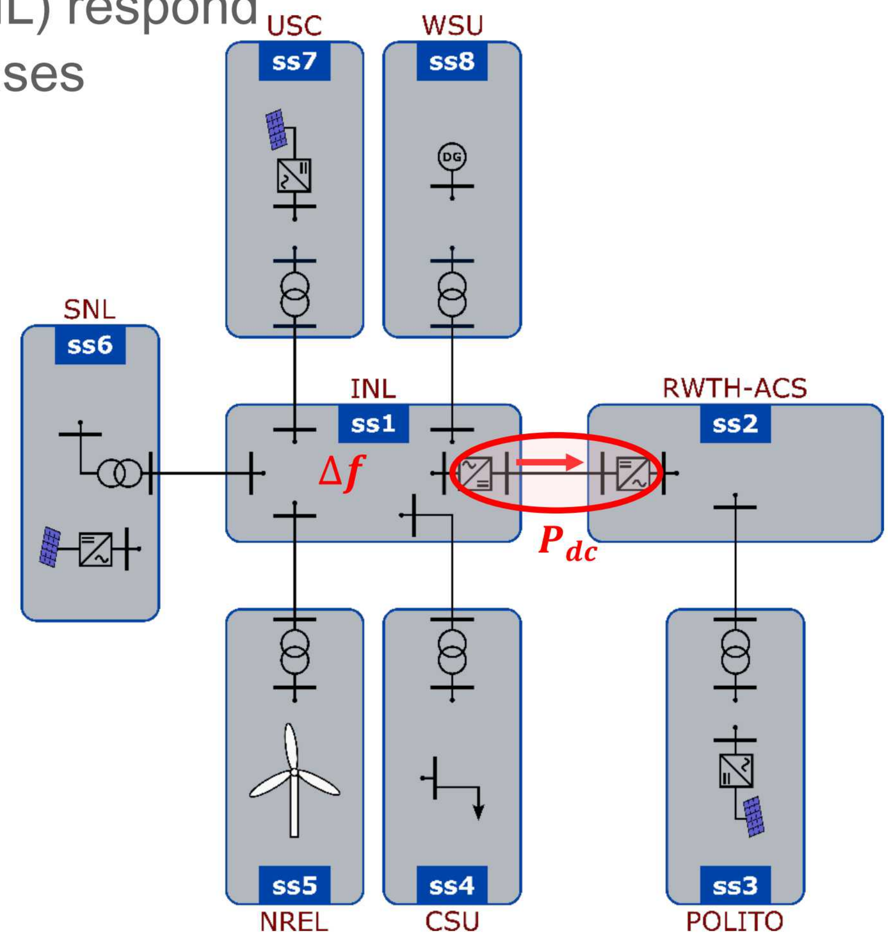


Simulation Results INL-RWTH

- Simulation results for the event:
  - Flow of power from INL to RWTH via HVDC
  - Key takeaway: optimal resource utilization
  - Power in the HVDC link is decreased by 25 MW
    - Generators at WSCC (INL) respond
    - System frequency increases

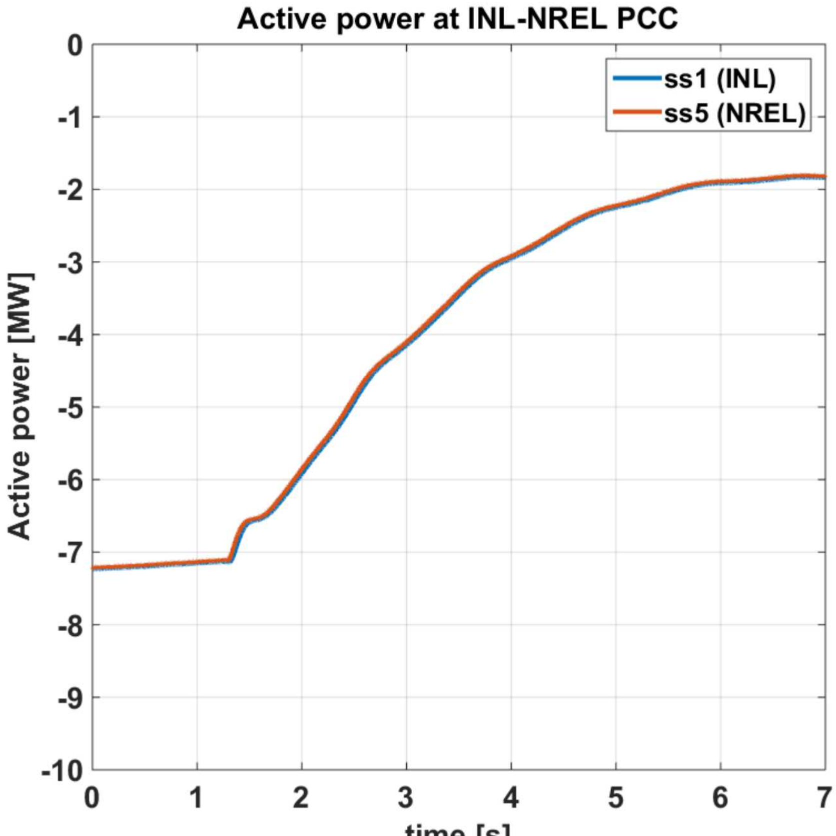


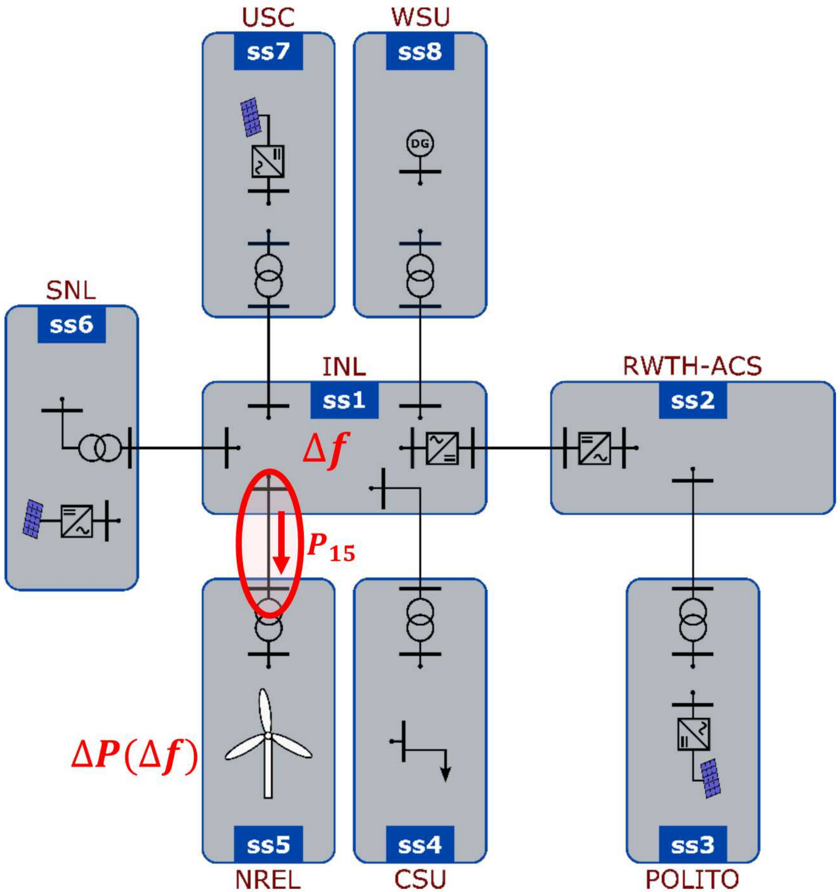




Simulation Results - NREL

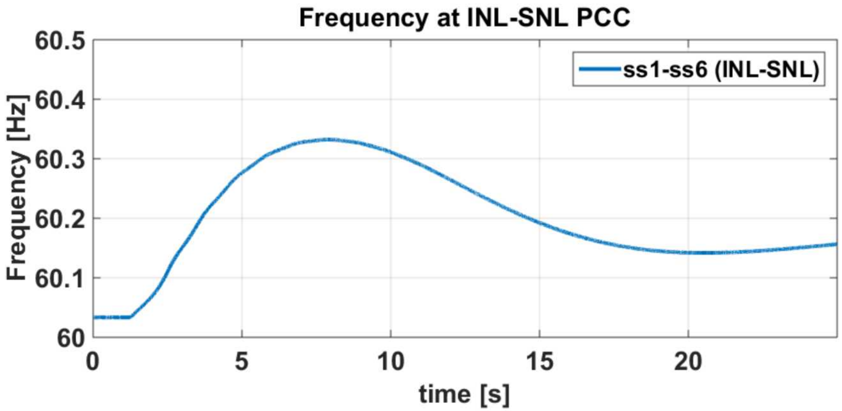
- Frequency support from a wind turbine
  - Over frequency event on account of over-generation
  - Key takeaway: stability and optimal resource allocation
  - Wind turbines respond based on droop settings
    - Negative sign indicates import to INL from NREL

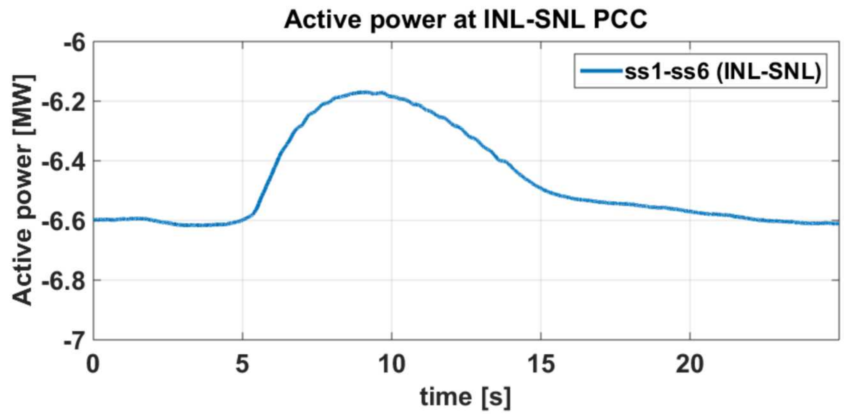


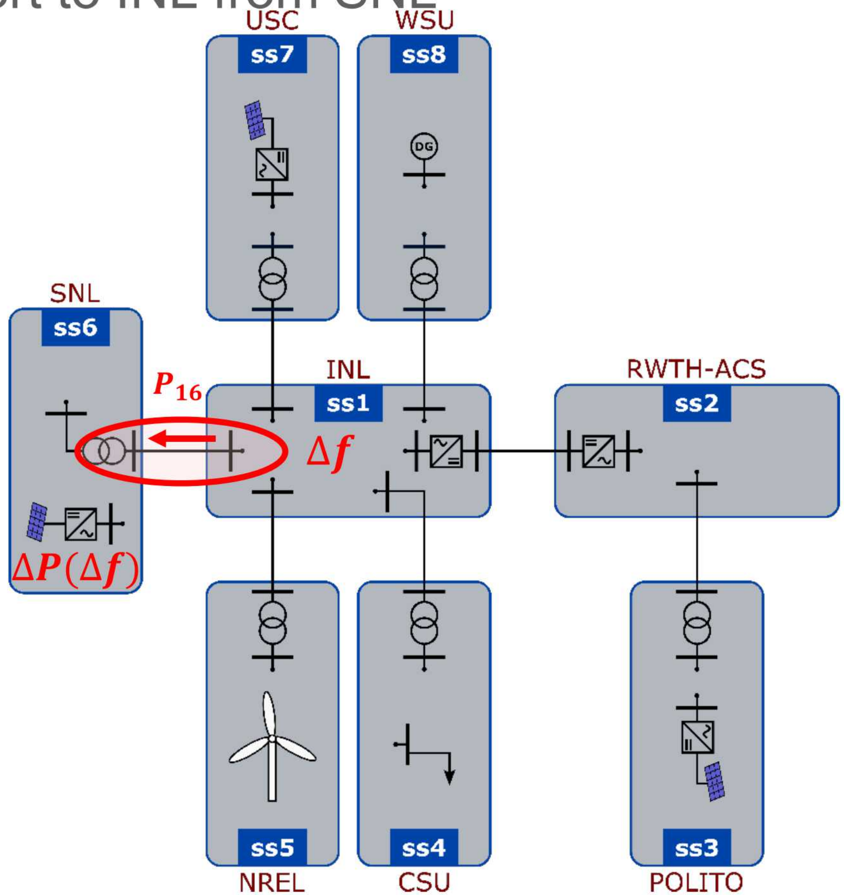


Simulation Results - SNL

- Frequency support from PV inverters
  - Over frequency event on account of over-generation
  - Key takeaway: stability and optimal resource allocation
  - Photovoltaic frequency–watt curve for frequency regulation and fast contingency reserves
    - Negative sign indicates import to INL from SNL

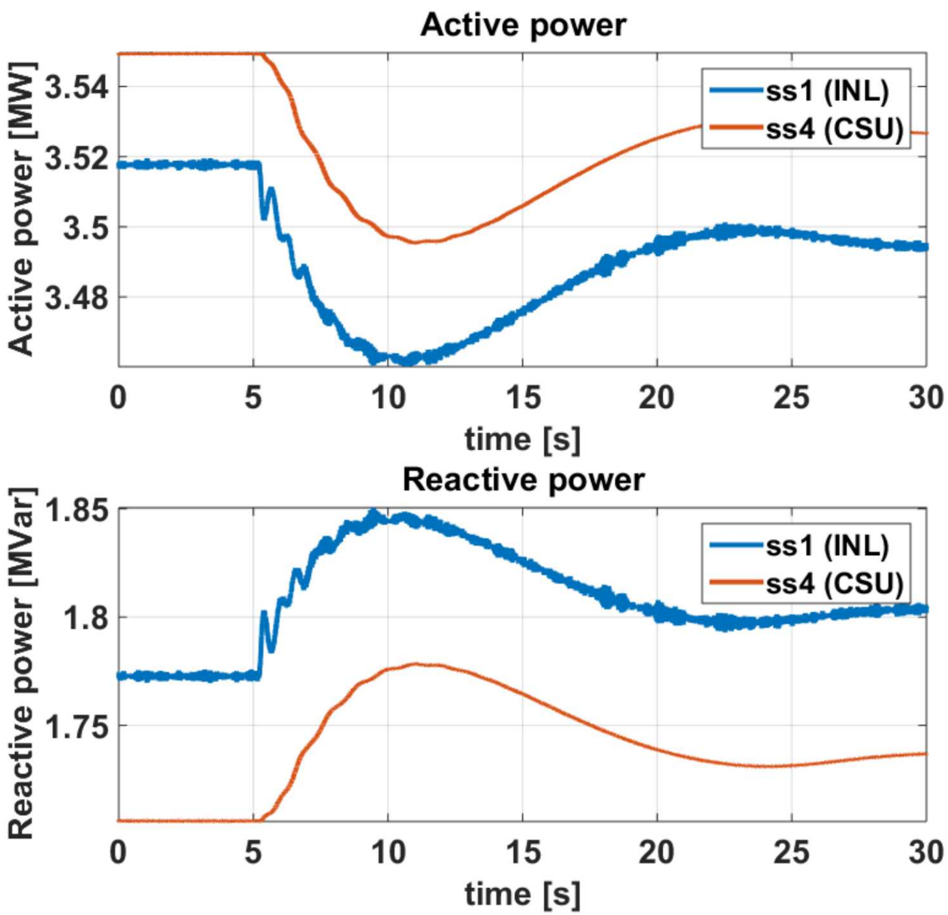


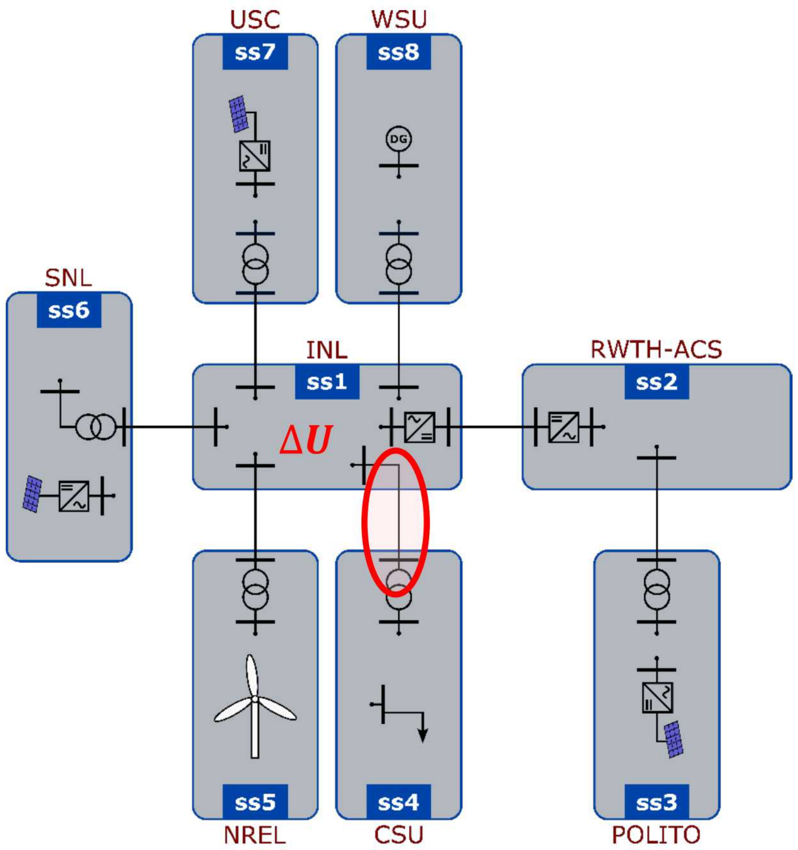




Simulation Results - CSU

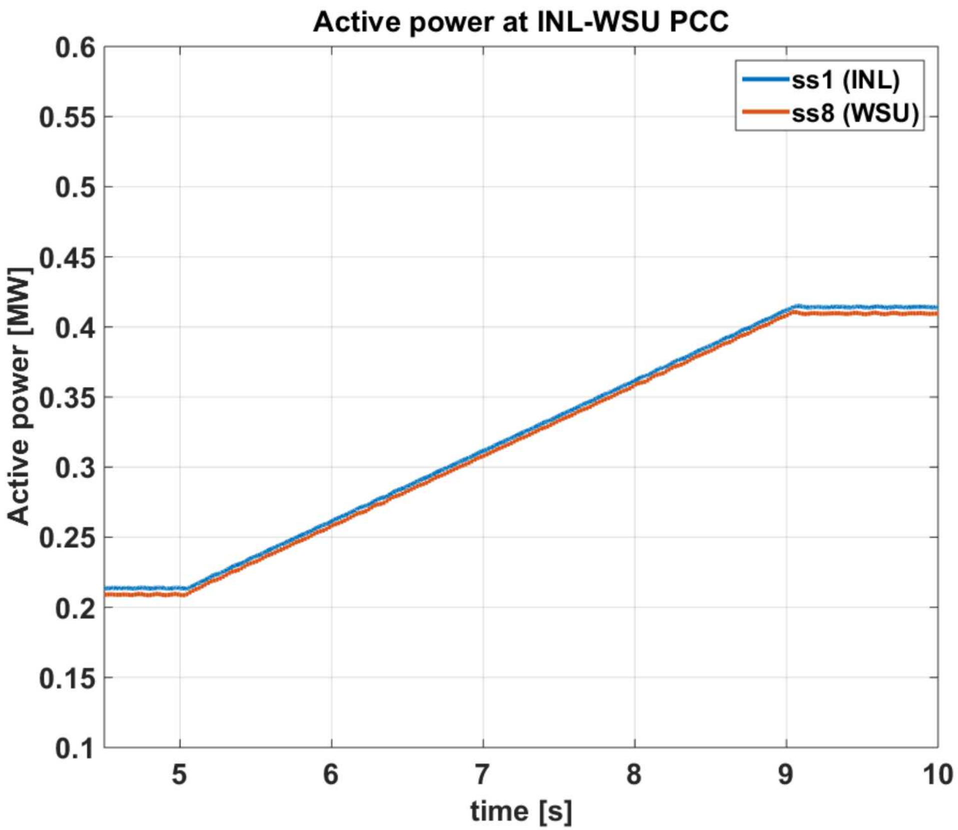
- Over frequency event due to loss of load initiated at the WSCC
  - Key takeaway: optimal resource allocation such as demand response using advanced load modeling
  - Next generation demand response programs using advanced resource allocation methods

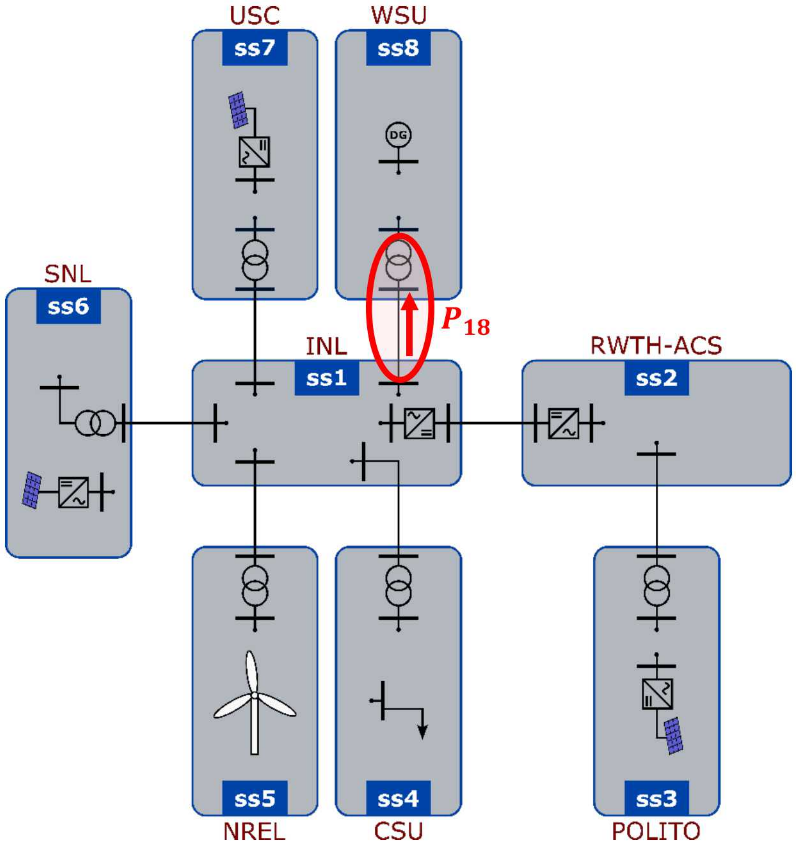




Simulation Results - WSU

- Loss of generation at the WSCC level
- Key takeaway: stability and resilience enhancement
- Battery charging from main grid to enhance the resiliency and reliability of the microgrid in a grid-connected mode of operation





Simulation Results RWTH-POLITO

- Disconnection of a generator in transmission network
  - LVRT capability of PV inverters
- Key takeaway: stability and fault ride through capabilities