OAK RIDGE National Laboratory

Grid Research Innovation and Development Center GRID-C

Madhu Chinthavali

Electricity Program Manager

Director GRID-C

U.S. DEPARTMENT OF ENERGY

ORNL IS MANAGED BY UT-BATTELLE LLC
FOR THE US DEPARTMENT OF ENERGY

Grid Research Innovation and Development Center

A constellation of facilities for grid research

Accelerate technology development to modernize the energy delivery system R&D for higher TRL (>3) advanced solutions development for a secure and resilient energy grid future

GRID-C leverages its Manhattan Project legacy of operating a utility-scale electricity distribution system, enabling validation of new technologies from the device level up to substations managing major loads.

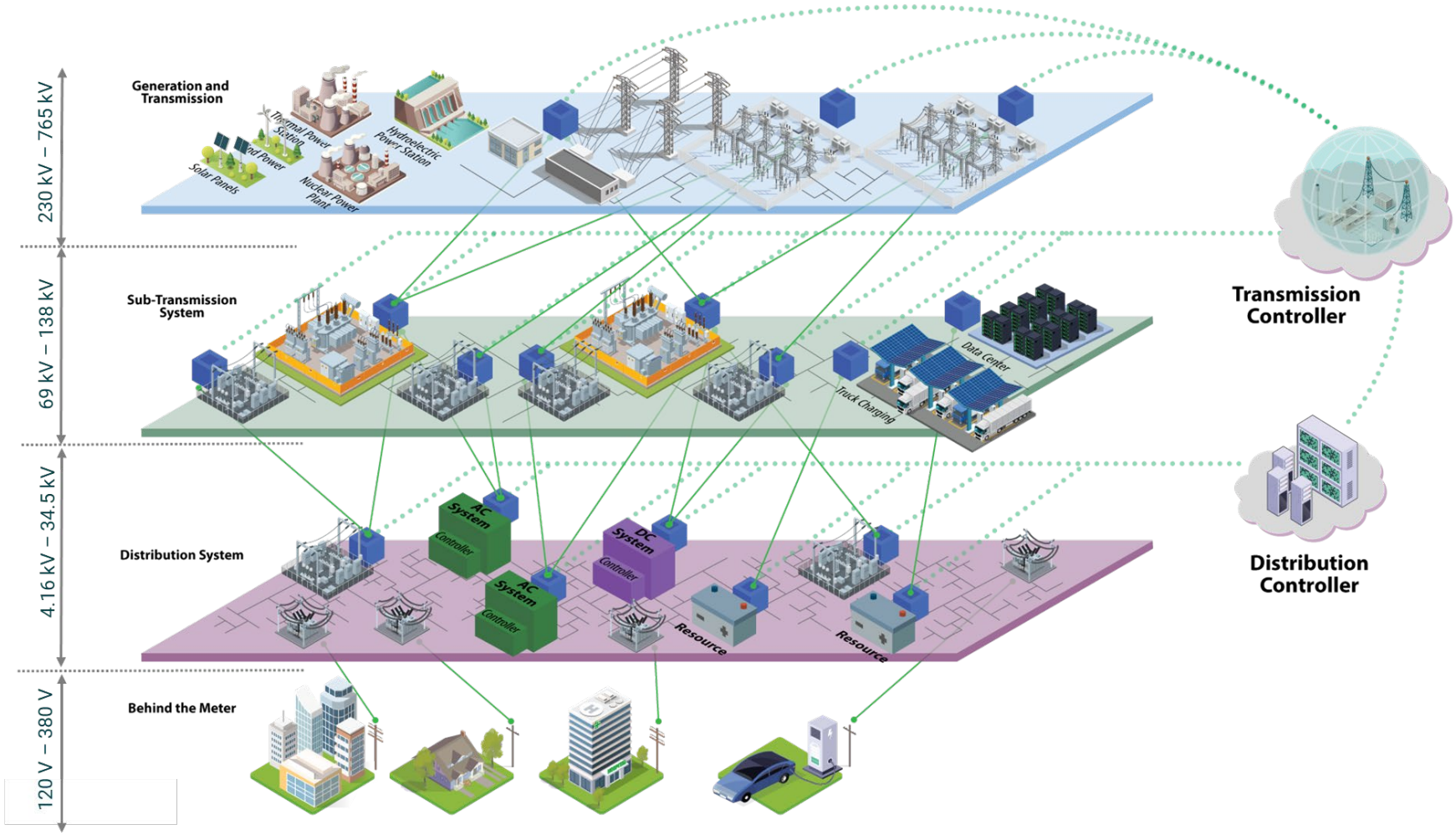
TECHNOLOGY DEVELOPMENT CENTER

Hardin Valley Campus

LAB AS A TEST BED

Main Campus

Driver & Opportunities

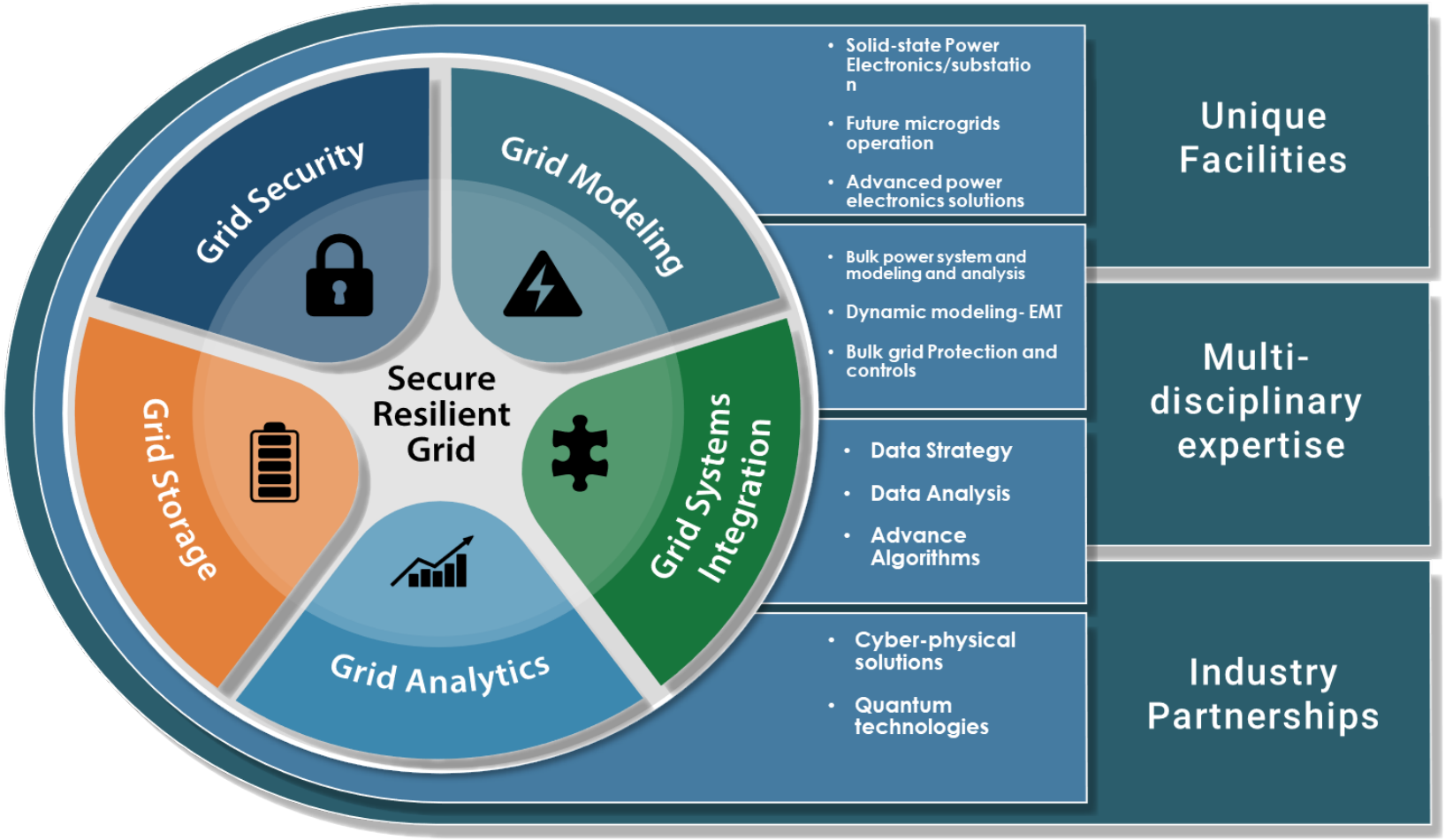


ORNL is working toward an autonomous grid using advanced sensors, data, controls, protection and security

- **Evolving infrastructure-** increasing load – Increasing generation
- Harnessing the **new data** from the assets
- Asset **integration** time
- Controllable assets -**flexibility-** understanding and operating
- Projected growth in **behind the meter** assets
- **Market** driven transactions for several owners
- **Supply chain** issues, Asset **security**

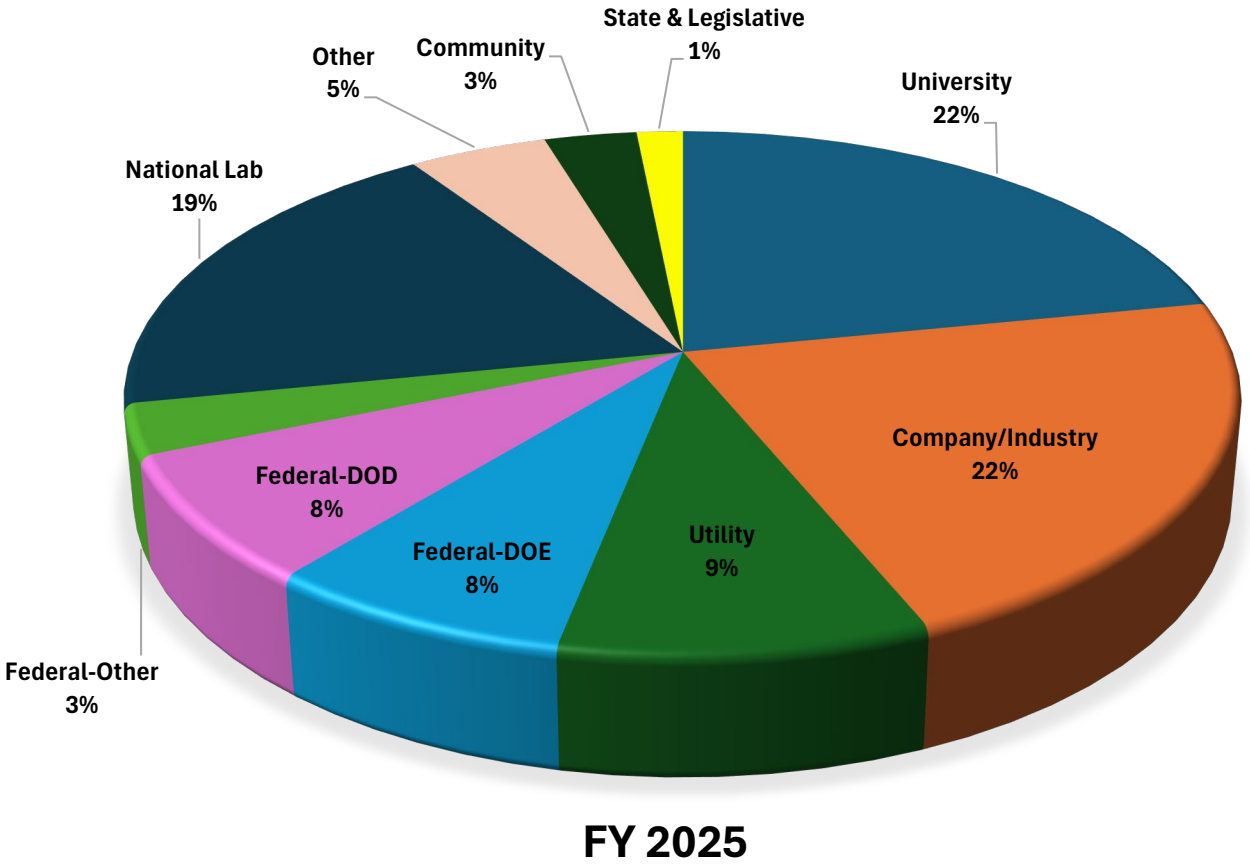
Technology Overview

Vision: *Develop initiatives that will leverage the investments and accomplishments of the R&D efforts supported by OE and GDO and position the grid portfolio to align with current trends and administrative priorities for the next 5 years.*



GRID-C Artifacts

GRID-C Tours



FY 2025

12+ R&D Groups, 75+ Personnel across four Directorates

34 Journal Publications

53 Conference Papers

20 Professional Society Service

15 Intellectual Property

26 Presentations

7 Software Platforms

1 R&D 100 Award

6 Awards

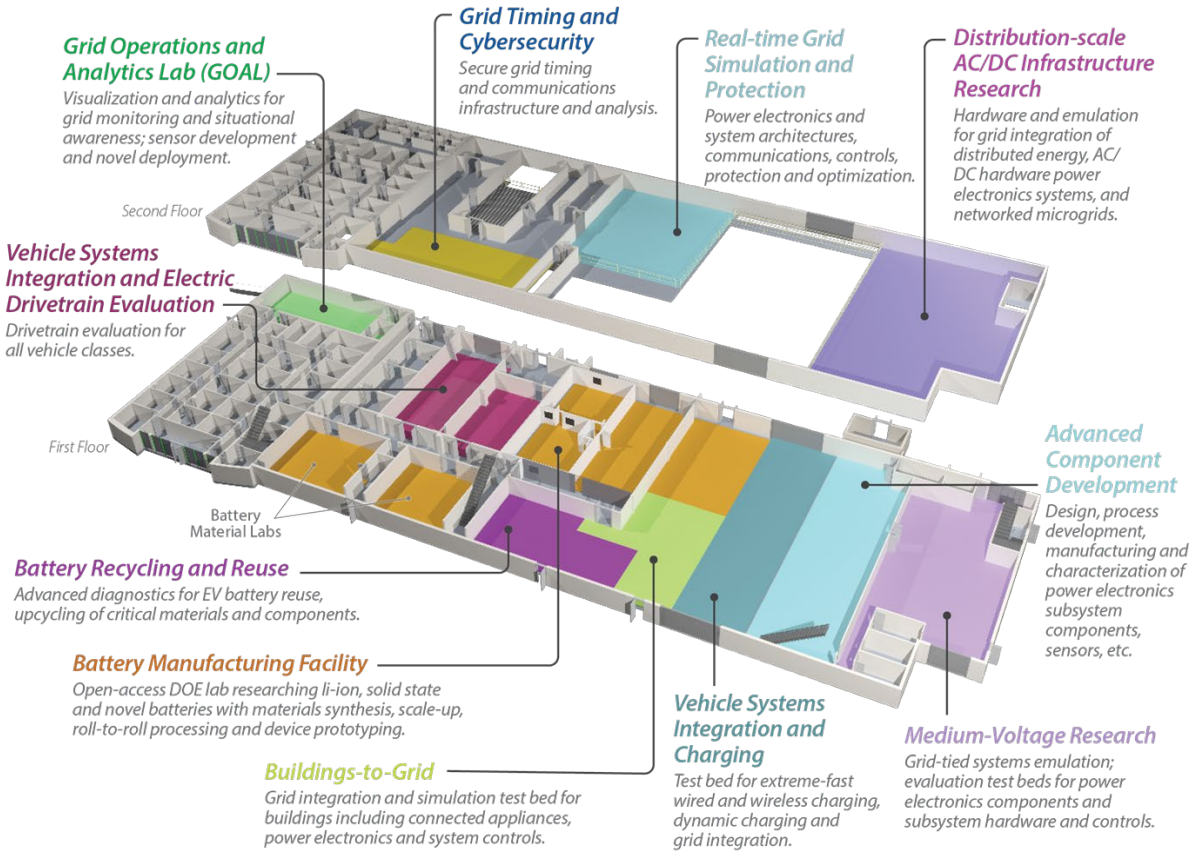
Grid Research Innovation and Development Center

ORNL's Grid-C HVC Facility: Physical testbeds for grid emulation and component integration

Grid-C uniqueness

- Advanced power electronics systems prototyping
- Integrated test beds for protection, controls, and cyber physical security evaluation
- Test platforms for assessing subsystems across range of power and voltage levels
- Advanced computing platforms for large-scale grid simulations

From components to subsystems under one roof

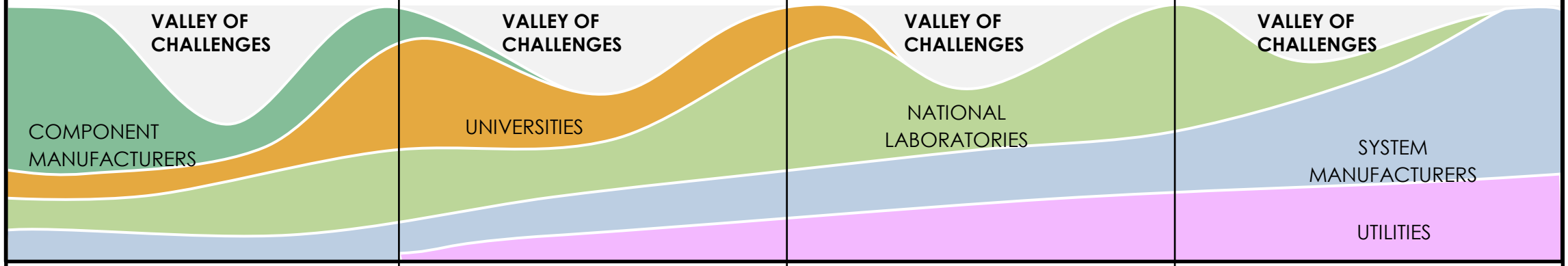


https://www.ornl.gov/gridc

GRID-C Technology Focus Areas: A Bridge Over the Innovation "Valley of Challenges"

Basic grid research ideation → Concept development → Development of prototypes and validation of concepts in simulation platforms → Evaluation of the concept utilizing the lab capabilities → Support the production environment → Demonstration @scale in laboratory test environments

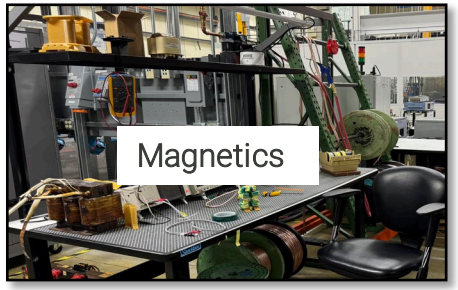
Advance Components & Power Stages	Advance Converter Systems	Resource Integration & Management Systems	Grid Integration & Demonstrations
Materials & Components, Intelligent power stages Embedded Controllers	Converter, Inverter, controls and protection, prototypes, Diagnostics, prognostics, Cyber security	Multi-stage converters, Software Platforms, Algorithms, Grid systems Architecture & Modelling	Grid Integration , Demonstration Use Cases



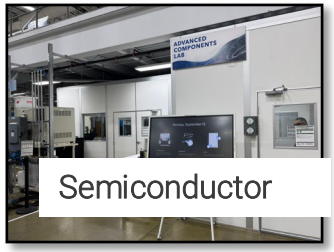
TRL 2–7	TRL 3–7	TRL 4–7	TRL 5–7

Accelerated GRID Technologies

Component to System Development



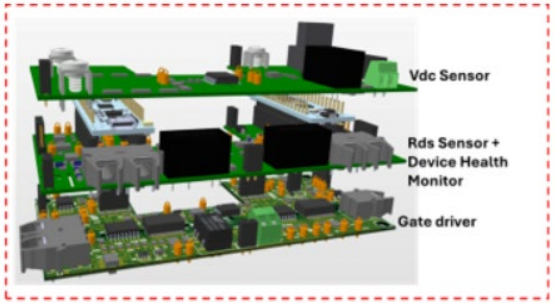
Custom Designs



Packaging

ORNL Control Board

Integrated Aux Hardware and Intelligence

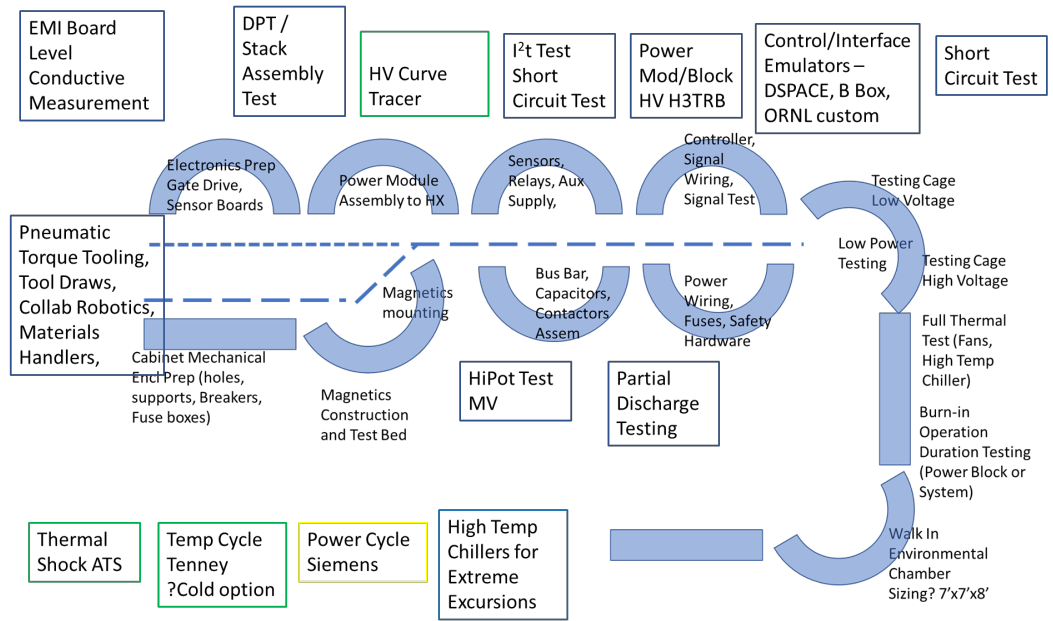


Characterization

ACCEPT Platform: Rapid characterization of semiconductors/gate drives/busbars

PE Stage Construction

PE System

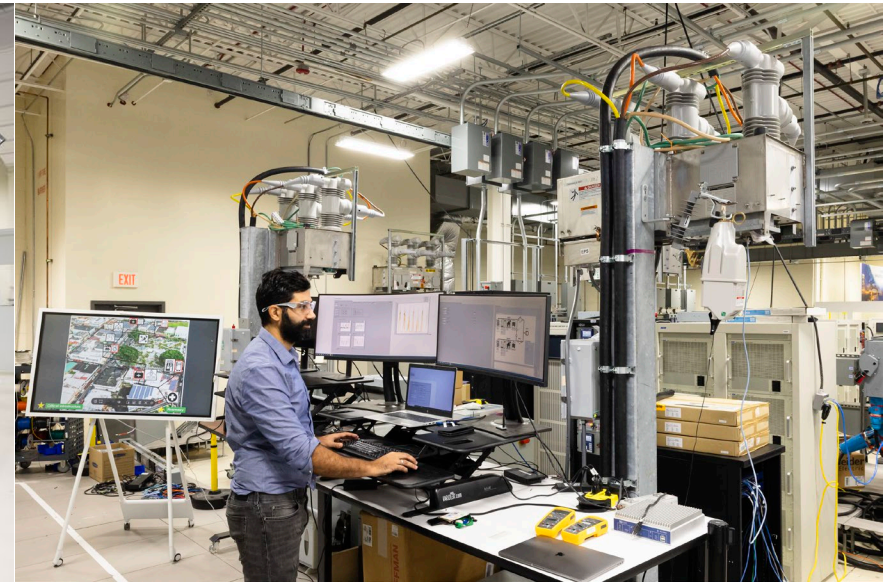


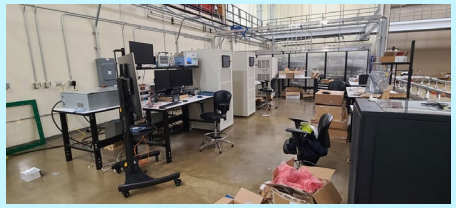
❑ Power Electronics Assembly

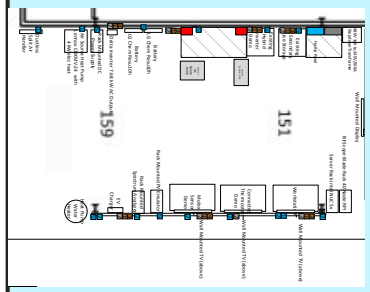
- ❑ Pilot level assembly for component and subsystem integration for inverter and converter prototypes
- ❑ Component and sub-system level testing and configuration
- ❑ Magnetics development and pulse testing
- ❑ Evaluate of board level metrics for drivers, controllers, or sensors
- ❑ Automated dispensing, coating, and spraying capabilities for board rework, cleaning, epoxy, or conformal coating

Test Beds for Systems for Low/Medium Voltage Hardware

- Unique Hybrid multi-node(18) AC-DC hybrid with ORNL developed hardware and software
- Medium voltage test bed for MV-Inverters
- Test bed for future Grid-tied Energy storage systems evaluation, DER interfaces and Power Electronics HUBs
- Test bed of protection, controls and cyber physical security evaluation of future substations
- Back to back 480V test bed for asynchronous grids



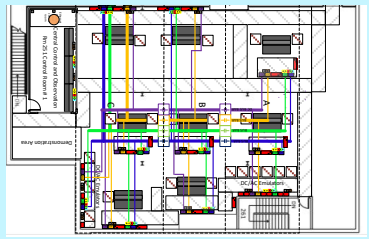




240 V/ 120 V Residential

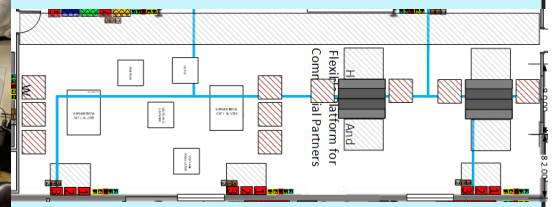
scale test bed

- 1 full scale residential node
- 50 home emulation



1 MW Hybrid AC-DC 18 Nodes test Bed DER, Energy storage, Commercial Buildings R&D

- Two 480 V, 1200 A AC lines
- 2 kV, 600 A DC



13. 8 kV Medium voltage test bed

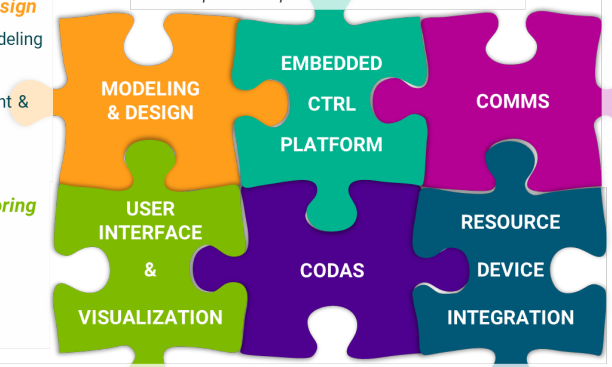
- Medium Voltage Power Converters
- Power flow control devices

Real-Time Systems Integration Lab: **RT-GEAR**

Embedded Control Platform
- Segmented control DSP board hardware
- Custom-built DSP code for converter control
- *Compatible IO ports with converter hardware*

RT Simulation Modeling & Design
- Modular and standardized modeling approach
- Optimal component deployment & core separation
- *Automated design script*

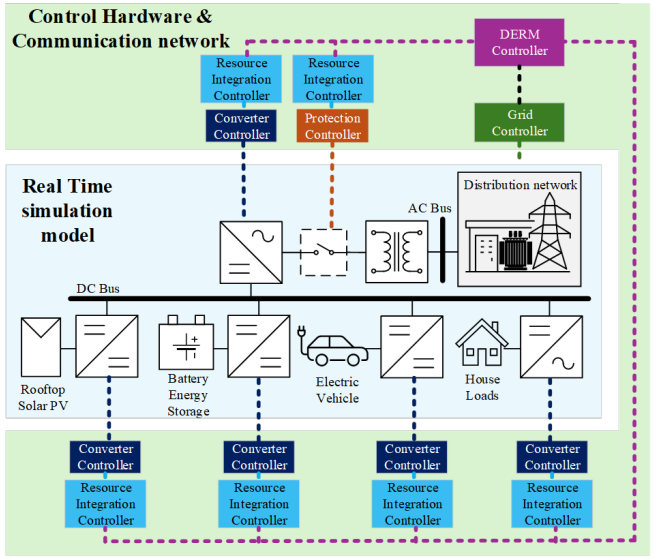
RT Operation & Monitoring
- Customized UI
- Control & Monitor
- Iterative simulation
- Report

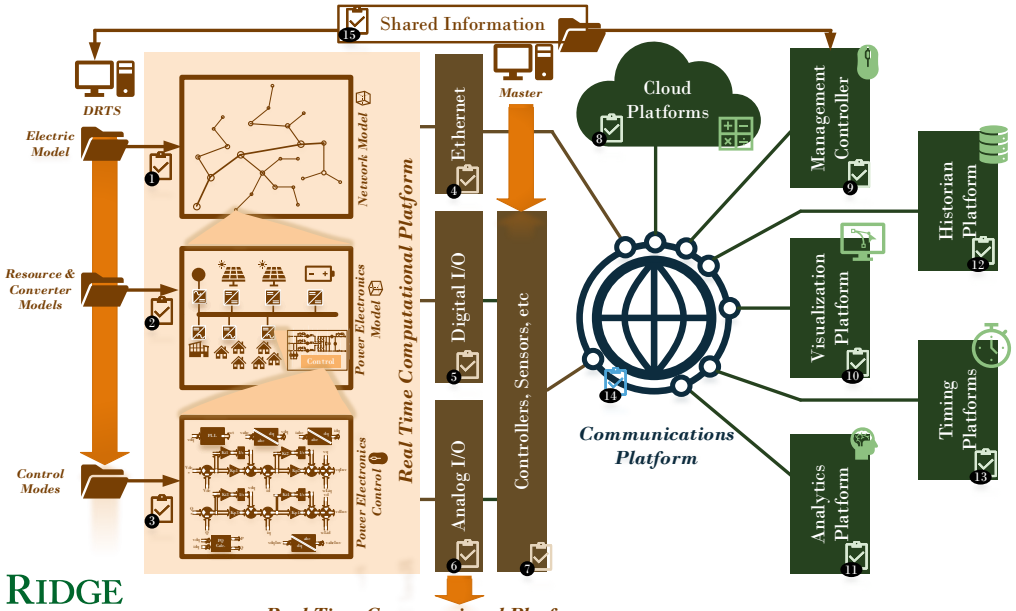


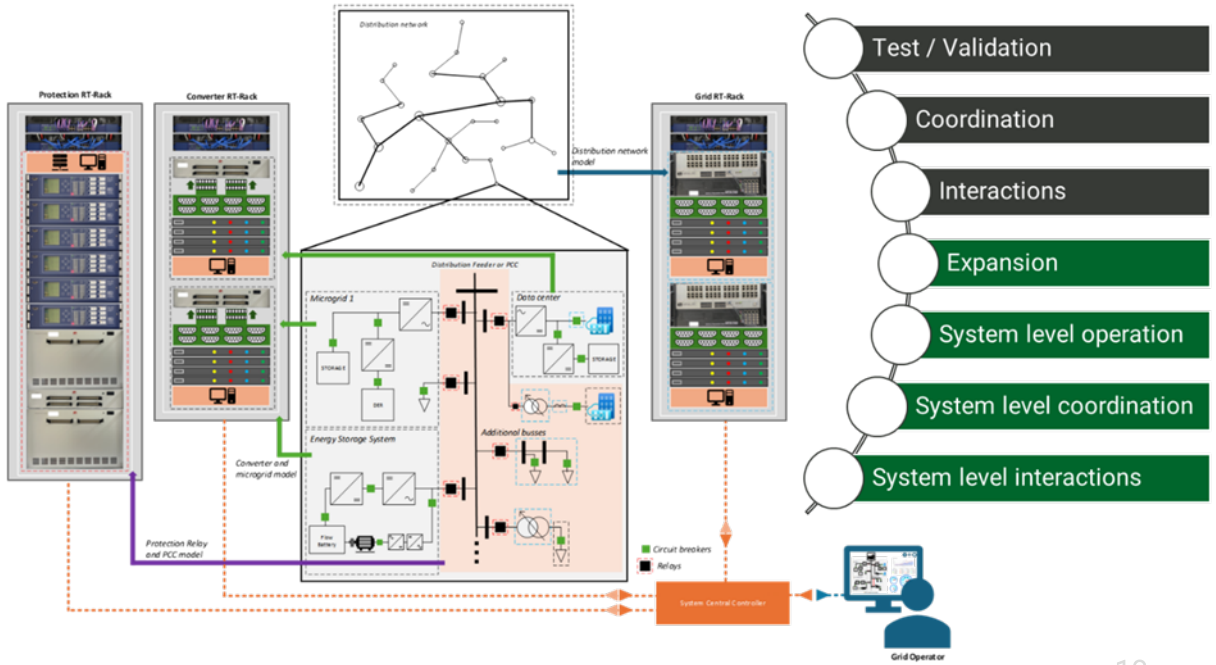
Communication Interface
- Tested and validated comms interface
- UDP, MQTT, MODBUS, CAN
- *Integration of converters/devices/resources*

Resource & Device Integration
- Plug-and-play identification through comms
- RT update of integrated system model configuration
- Integration of DERs, protection, and distribution feeder

Control and Optimization using Distributed Agent-based System (CODAS)
- Operational integration platform
- Operation & control optimization including Start-up & Shut-down optimization
- DER/Resource management *& converter control modes & protection scheme*
- *Autonomous transitions between on/off grid modes*







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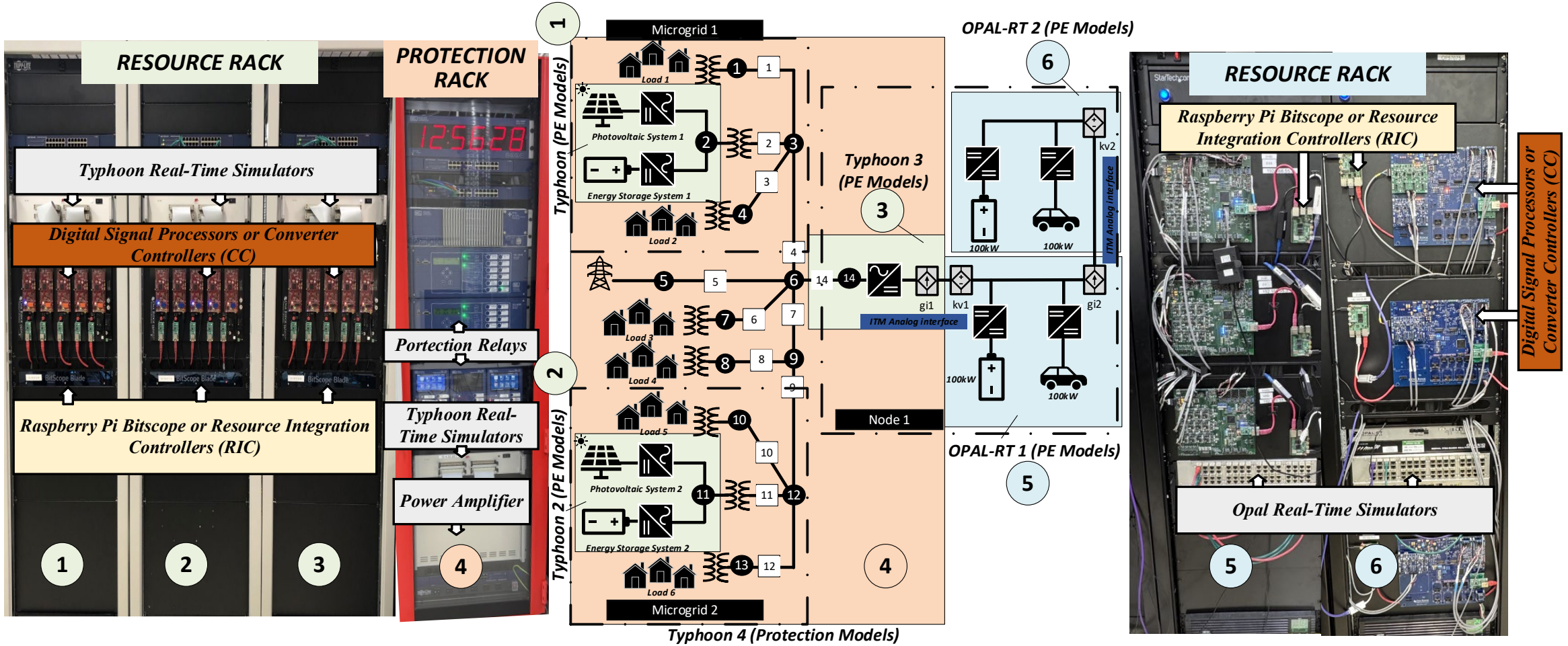
Real-Time Systems Integration Lab: **RT-GEAR**

- Multi-platform integration techniques scaling for future power system validation platforms
- 6 Simulators + 32 Controllers

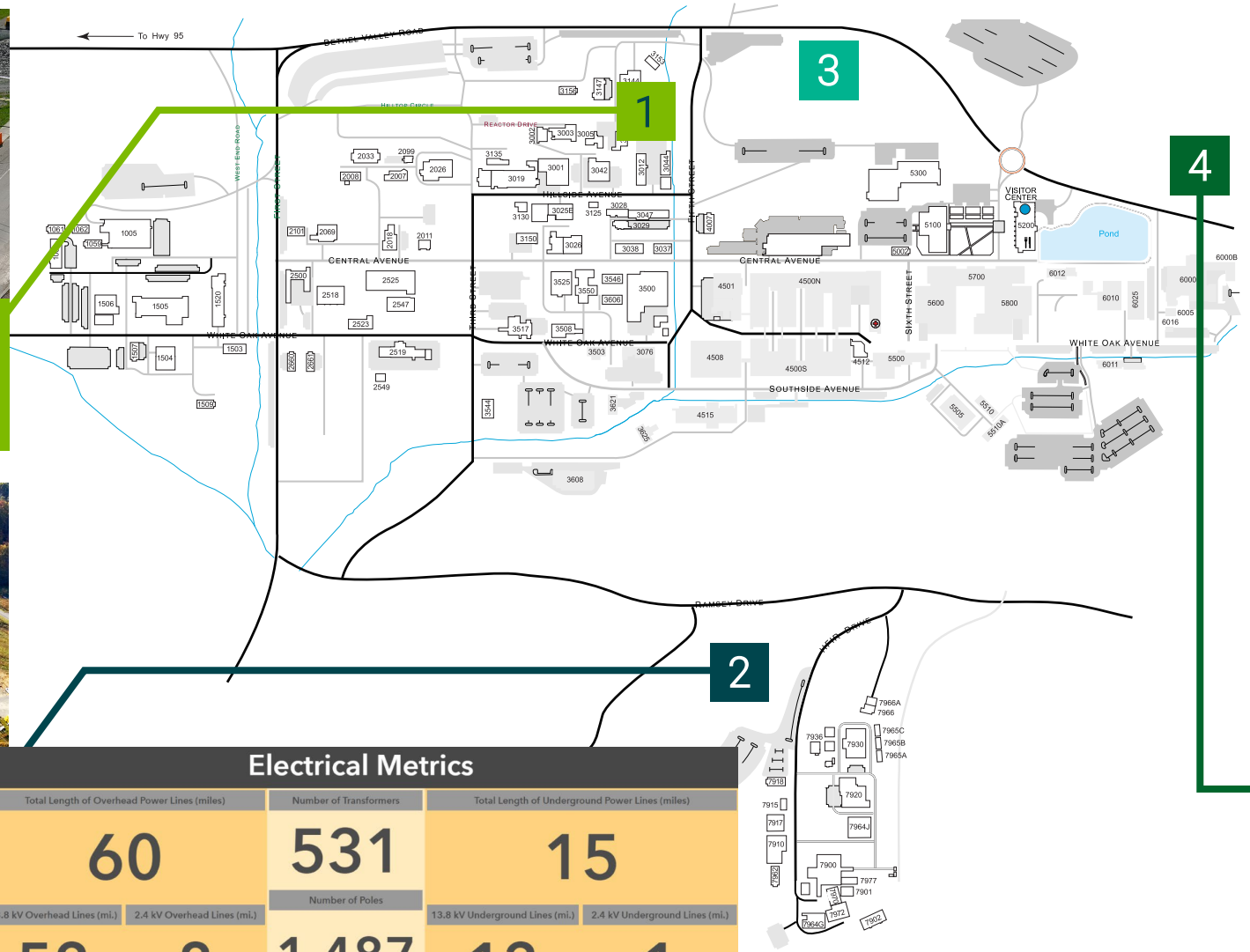


Controller Hardware in the Loop Expansion

Lab as a test bed : ORNL Main Campus

DECC
Distribution sensor testbeds and validation in hardware

Substation sensor testing



Electrical Metrics

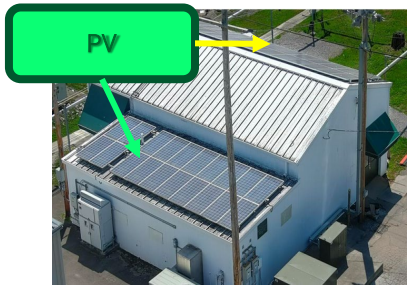
Total Length of Overhead Power Lines (miles)		Number of Transformers	Total Length of Underground Power Lines (miles)	
60		531	15	
13.8 kV Overhead Lines (mi.)	2.4 kV Overhead Lines (mi.)	Number of Poles	13.8 kV Underground Lines (mi.)	2.4 kV Underground Lines (mi.)
52	8	1,487	13	1
Number of Connections (under review)		Number of Buildings with Electricity (under review)	Number of Meters	
566 (Can be more than one per Building)		358	245	

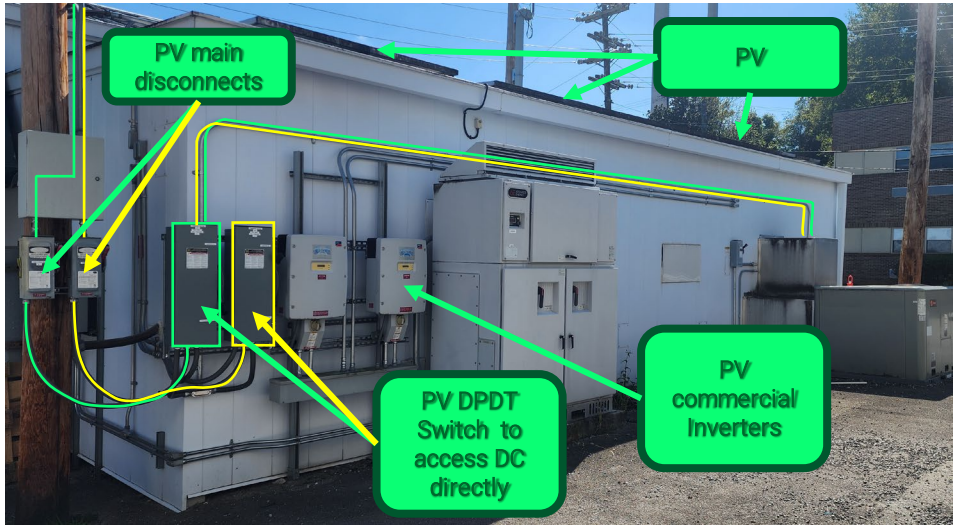
Fully instrumented substations with sensor testing

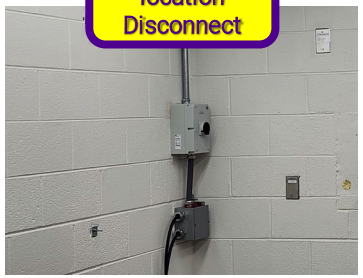
PCAT
Novel conductor testing

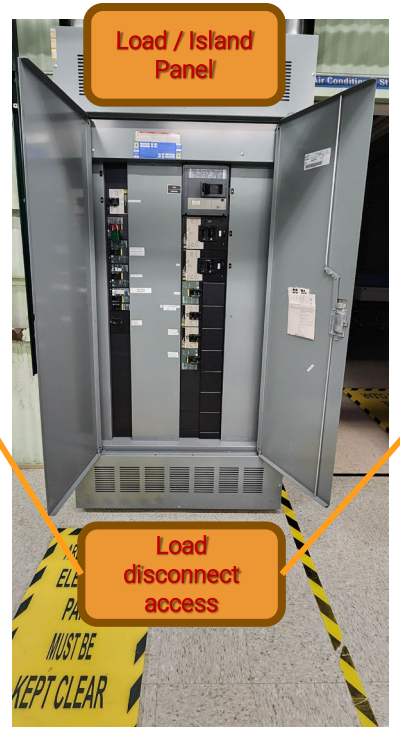
Feeder Network for R&D Demonstration on ORNL Campus

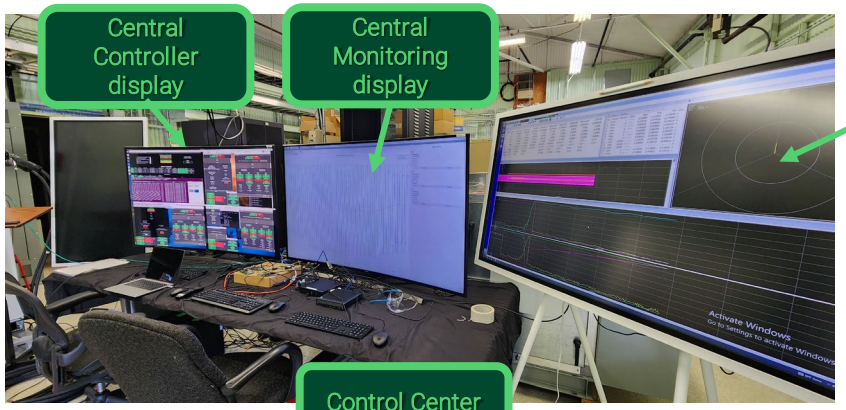
Grid Edge Node Test Bed Infrastructure











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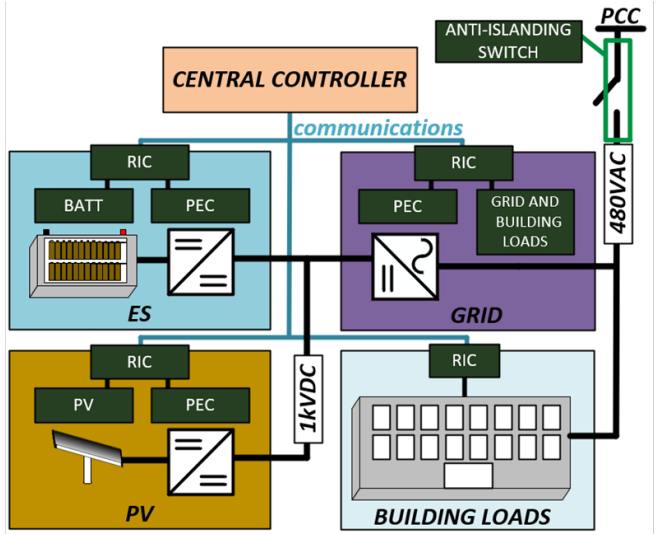
Grid Edge Node Demonstration on ORNL Campus

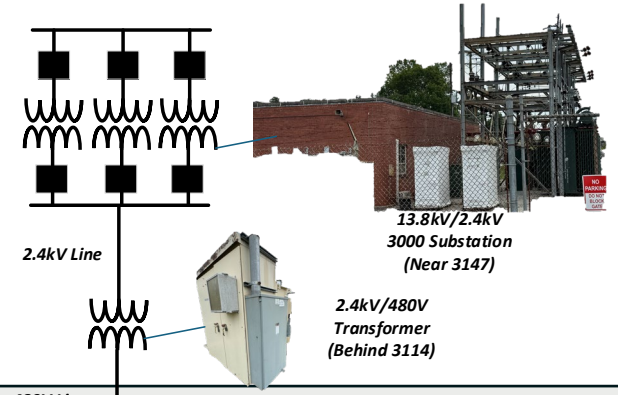
Energy Storage
(500V to 665V, 30kW,144kWhr)
P Regulation 900 Vdc

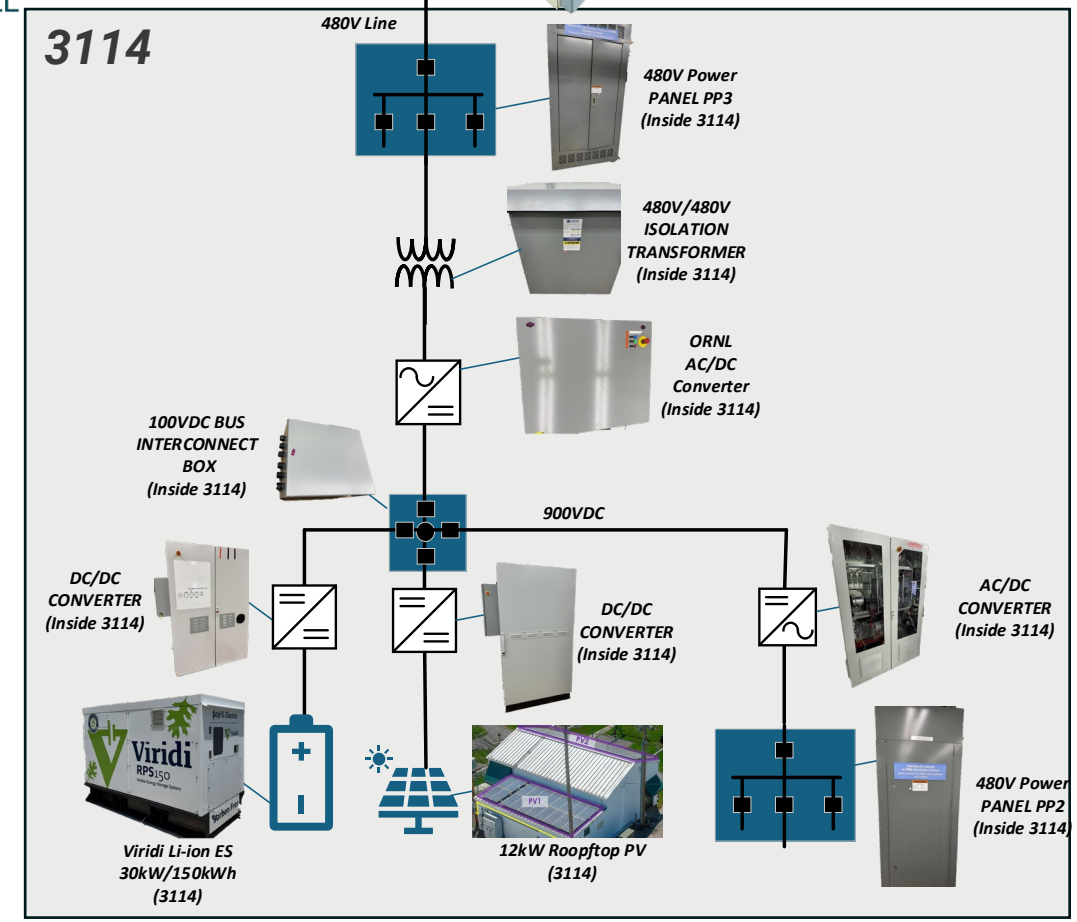
PV (6.97kW, 12s2p)
String specs
(Isc:8.43A, Voc:535.2V)
Hanwha (HSL72 280W)
MPPT



Grid-tied inverter Vdc Regulation
(900VDC to 277VLN, 30kW)

Building Loads – 480VLL
Forecasting

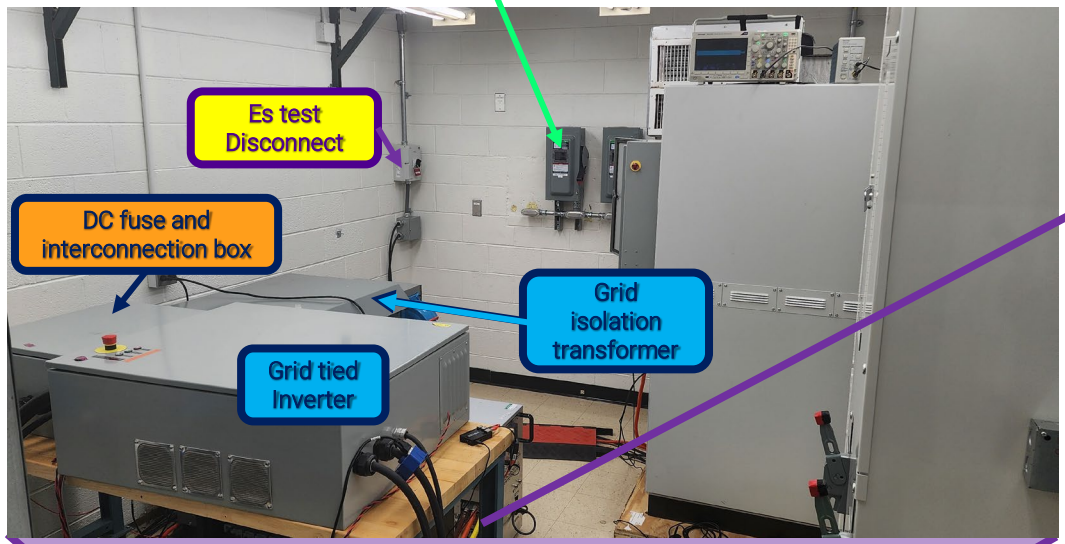


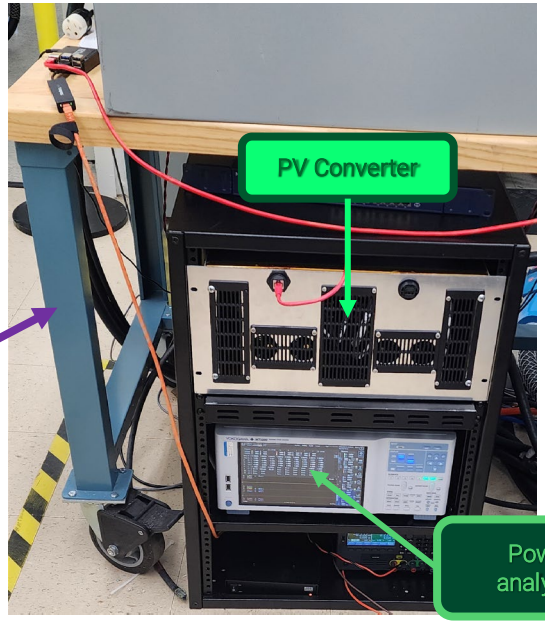


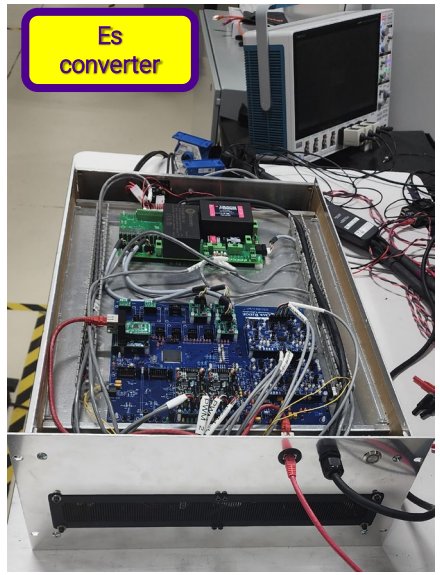
Physically connected to ORNL electrical networks:

- Hub/Node is connected to AC Panel in 3114 and exposed to voltage/current from electric grid (harmonics & transients)
- 3114 Facility is fed by transformer (behind the building) @480V from a 2.4kV feeder line
- 3000 Substation contains switchgear and transformers (2.4kV / 13.8kV) fed from ORNL distribution network @13.8kV
- Main campus substation contains switchgear and transformers (13.8kV / 161kV) fed from TVA transmission @161kV.

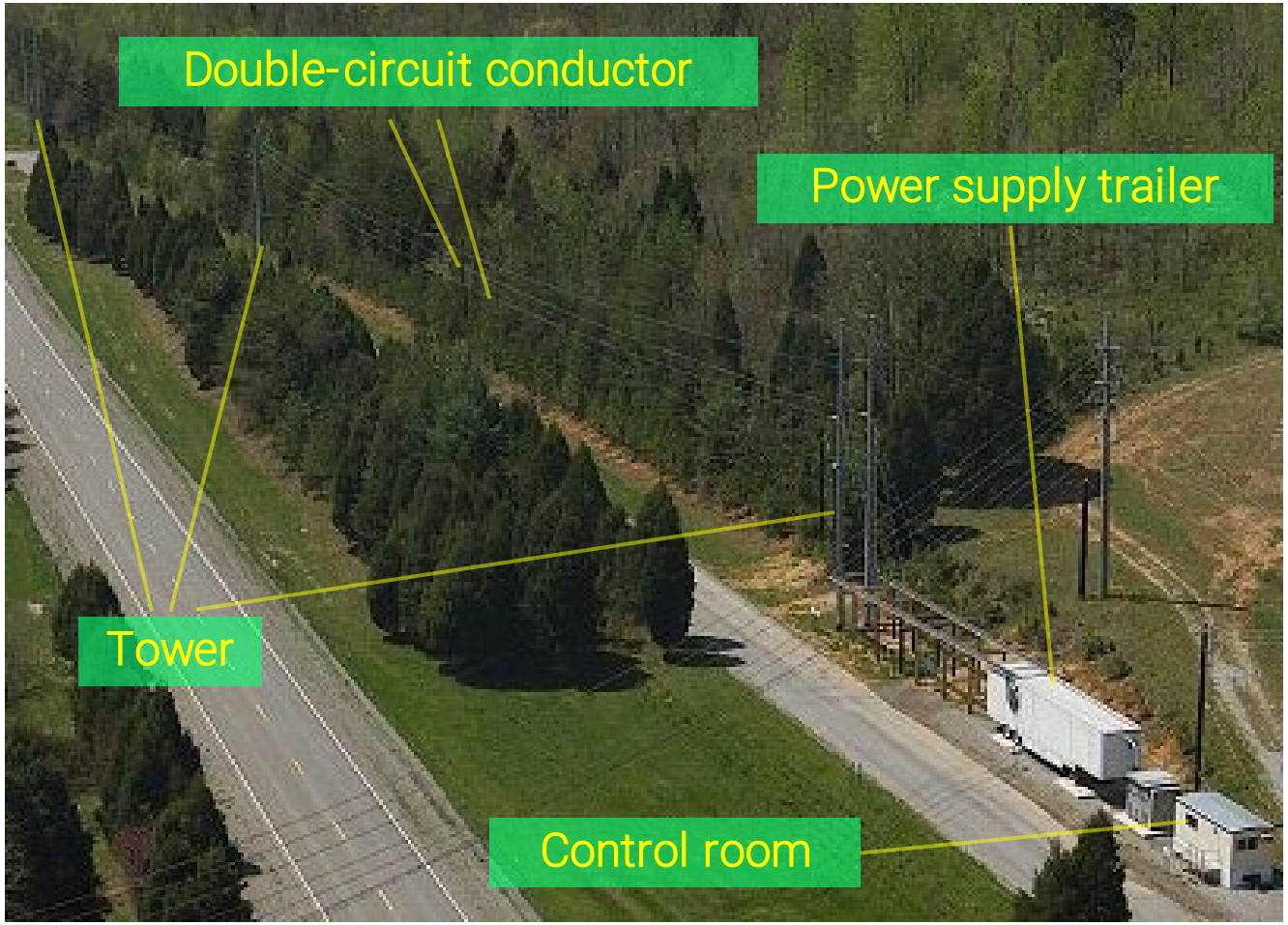
Autonomous Grid Node Demonstration

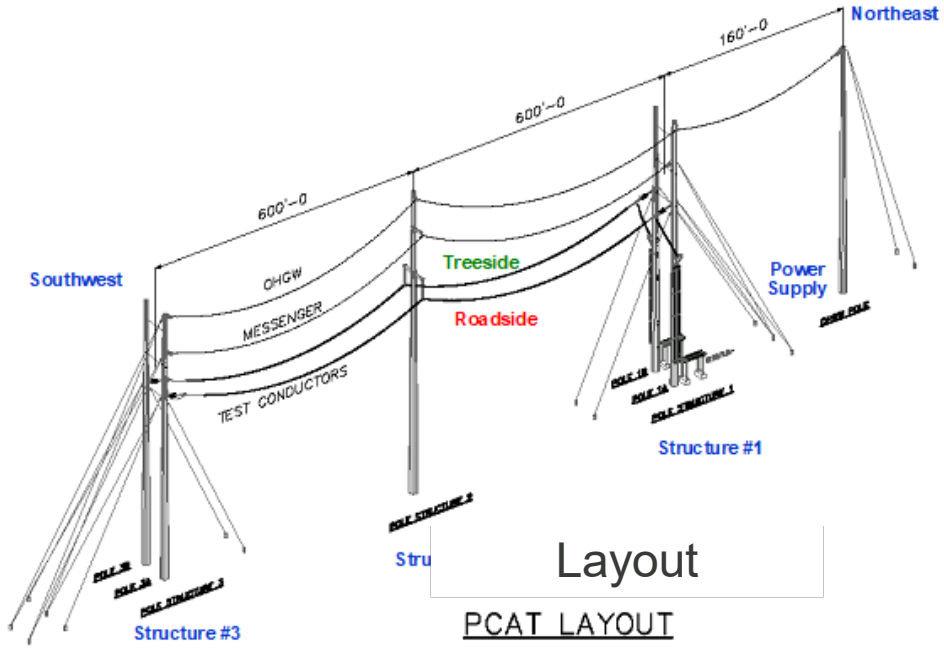




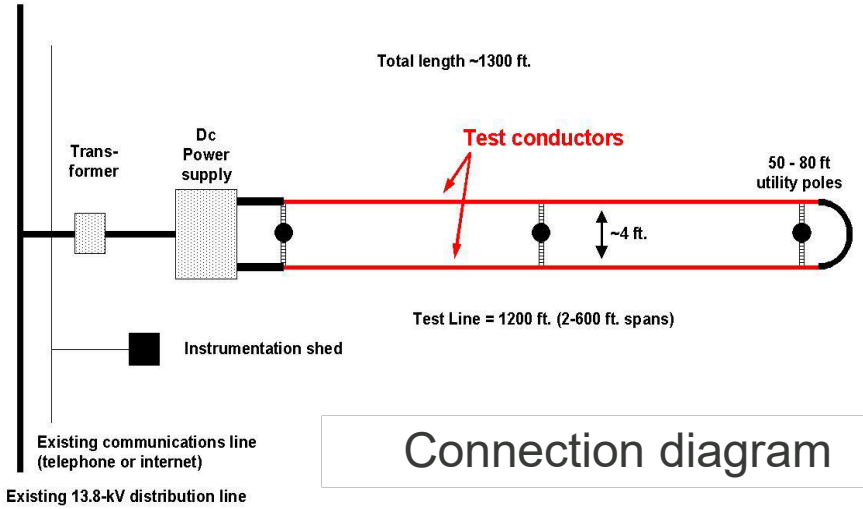


PCAT: PowerLine Conductor Accelerated Testing Facility





Layout



Connection diagram

BIG SCIENCE BIG GOALS

Science: Demonstrate power electronics systems, sensing, analytics, protection and controls systems that will enable resilient autonomous grid operations that include medium voltage distribution, mixed AC/DC systems, and dynamic microgrids.

ORNL is supporting DOE's PACE Consortium

Platform for partner research institutions, utilities, and industry manufacturers

Integration

Reliability

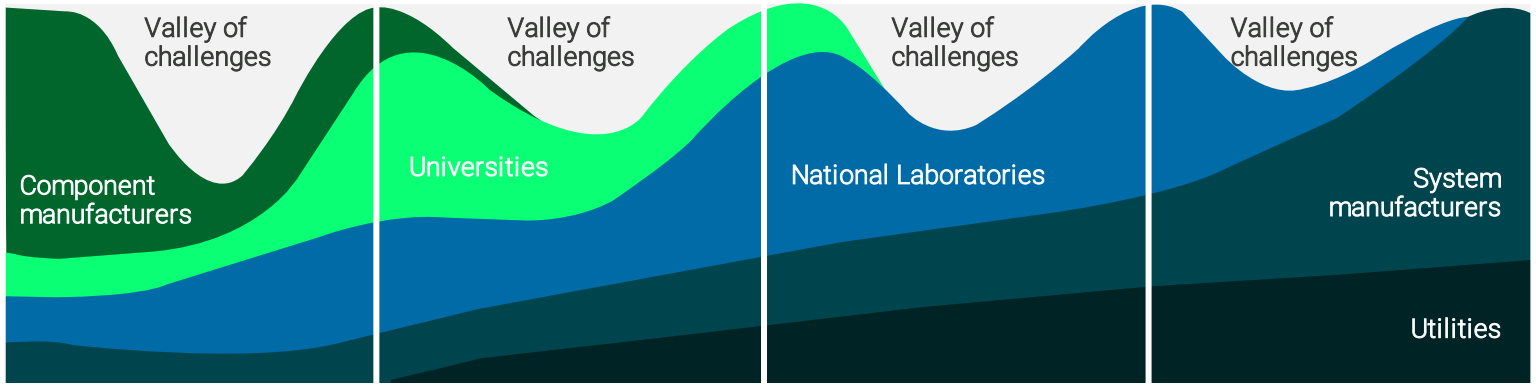
Supply Chain

Overcoming these barriers will lead to:

Security and resiliency

New markets and domestic manufacturing opportunities

Component R&D	Sub Systems R&D	Systems R&D	Field Validation
Materials and components, embedded controllers	Power stages and sub-system prototypes	Auxiliary systems, software platforms, algorithms, system prototypes	Pilot demo use case

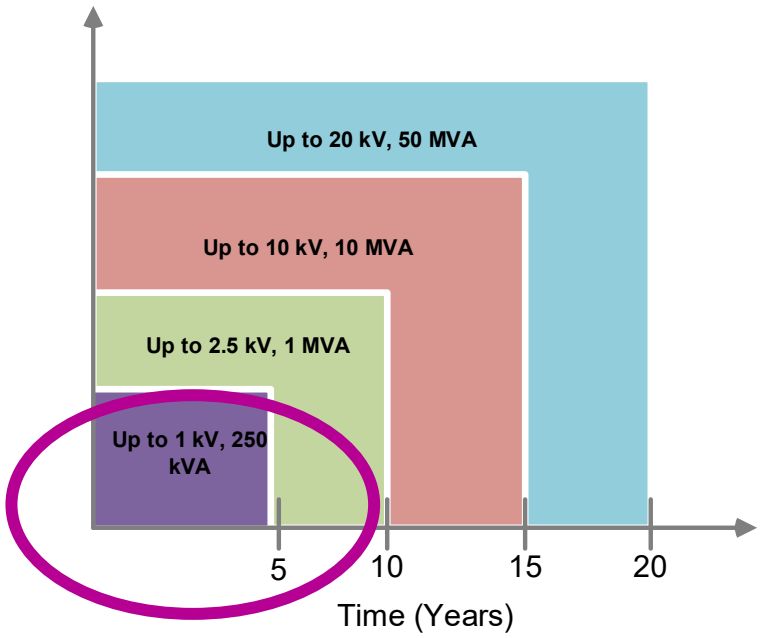


TRL 2 – 7 | TRL 3 – 7 | TRL 4 – 7 | TRL 5 – 7

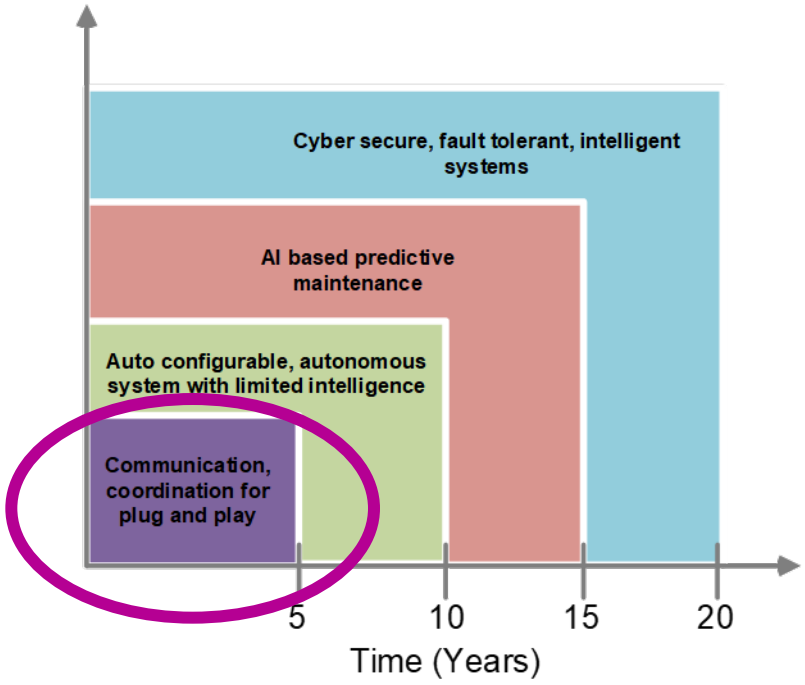
Accelerated power electronics technologies

Technology Metrics and Targets 2020-2040

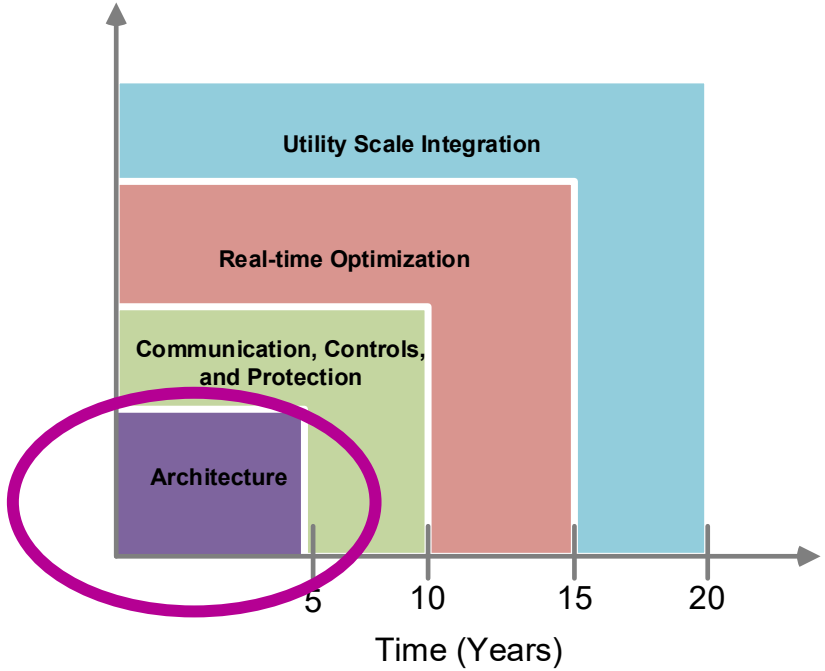
Hardware



Software and Intelligent PE Systems



Grid Integration

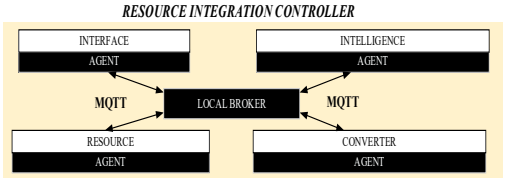


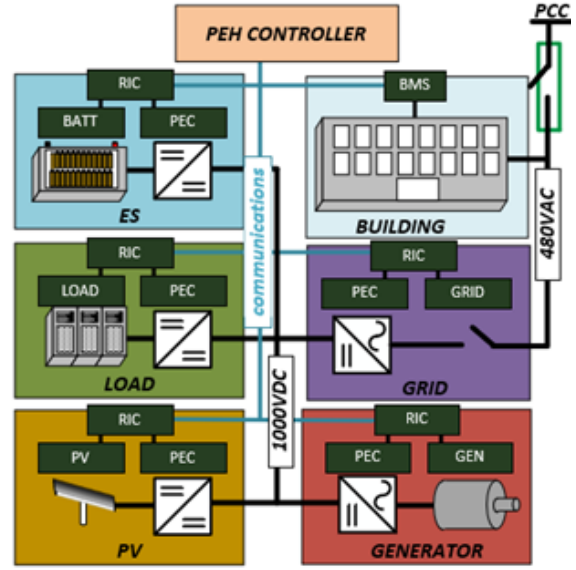
COST/AFFORDABILITY

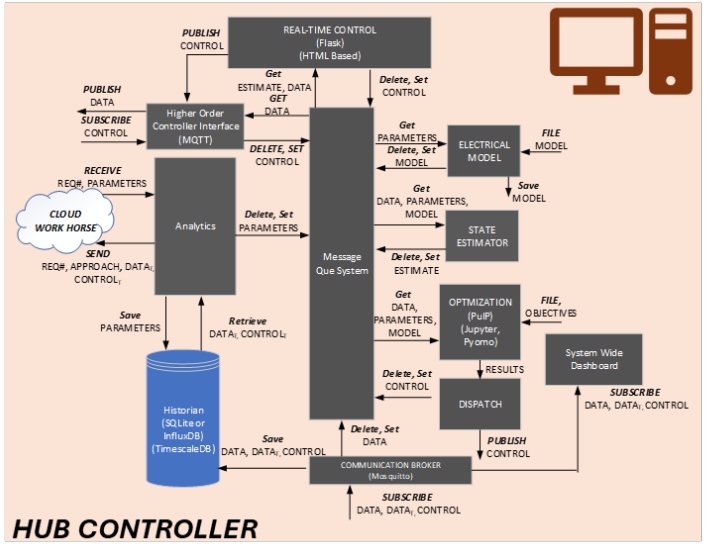
RELIABILITY

INTEGRATION

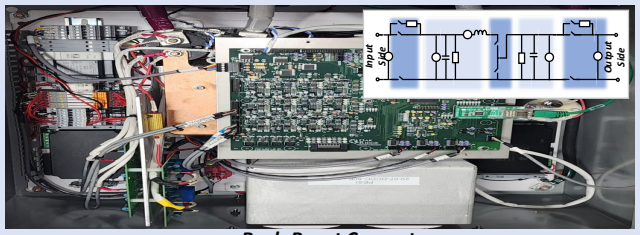
Grid Node with Real Time Decision Making Capability – Field Pilot Demonstration @Southern Company



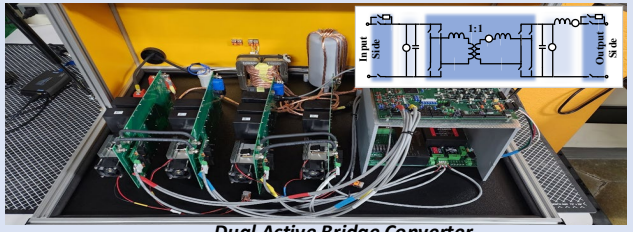




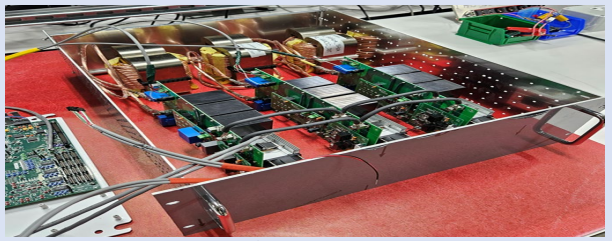
HUB CONTROLLER

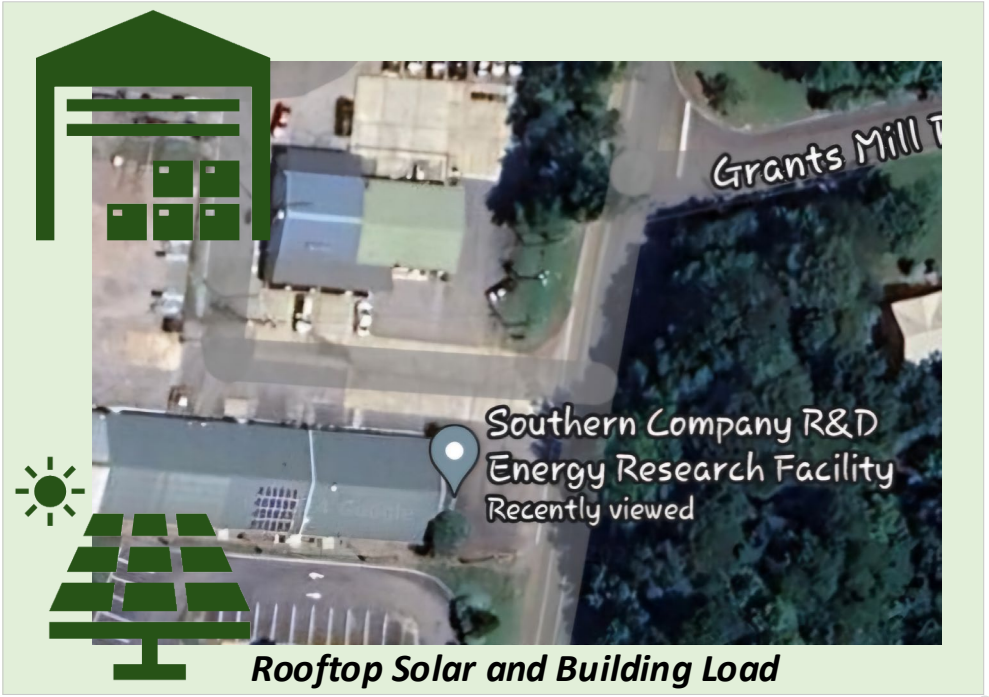


Buck-Boost Converter



Dual Active Bridge Converter

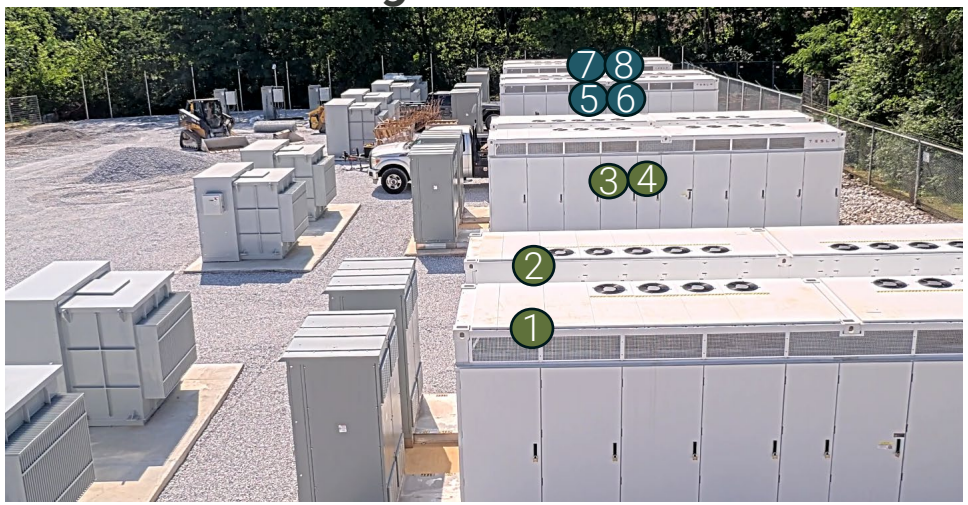

AC/DC Converter



Rooftop Solar and Building Load

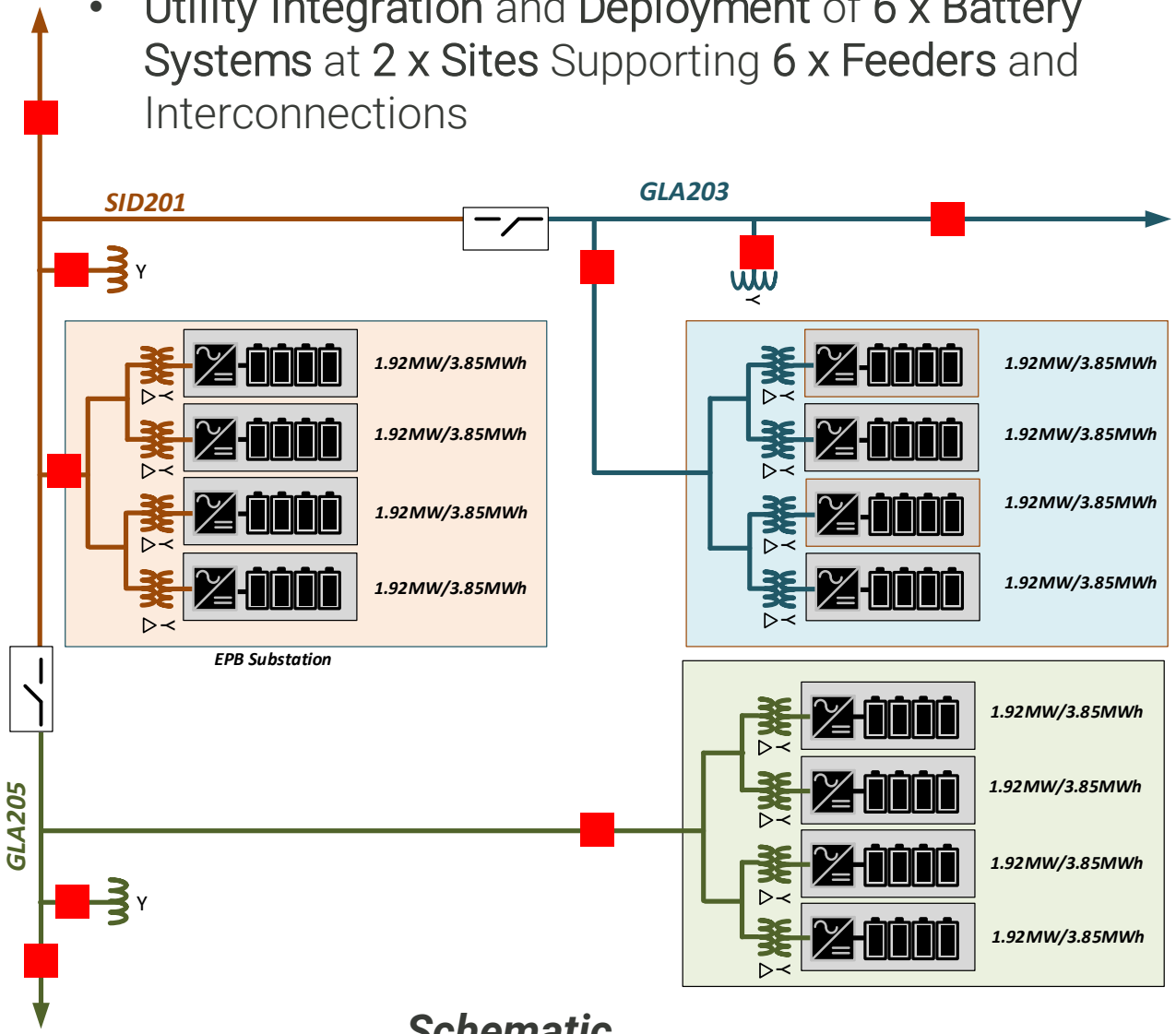
Networked Microgrid Demonstration with EPB

Google Earth



Deployment

- Utility Integration and Deployment of 6 x Battery Systems at 2 x Sites Supporting 6 x Feeders and Interconnections



Schematic

Integrated Grid Systems Data Center as a Grid Asset - Edge to Hyperscalers

Objectives

- Power and energy Infrastructure architectures
- Energy affordability and Energy modeling
- Grid modeling with focus on EMT simulations
- Advanced long duration storage technologies
- Advanced Thermal Technologies

Challenges

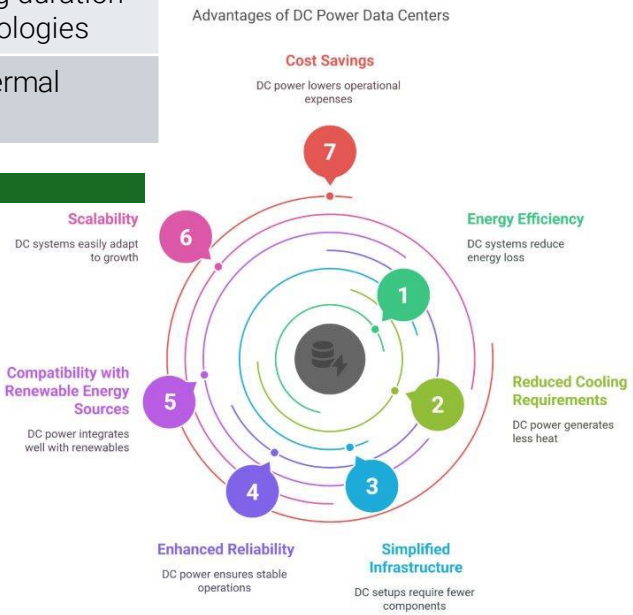
- Lack of data and benchmarked performance metrics
- Suppliers resistance to changes

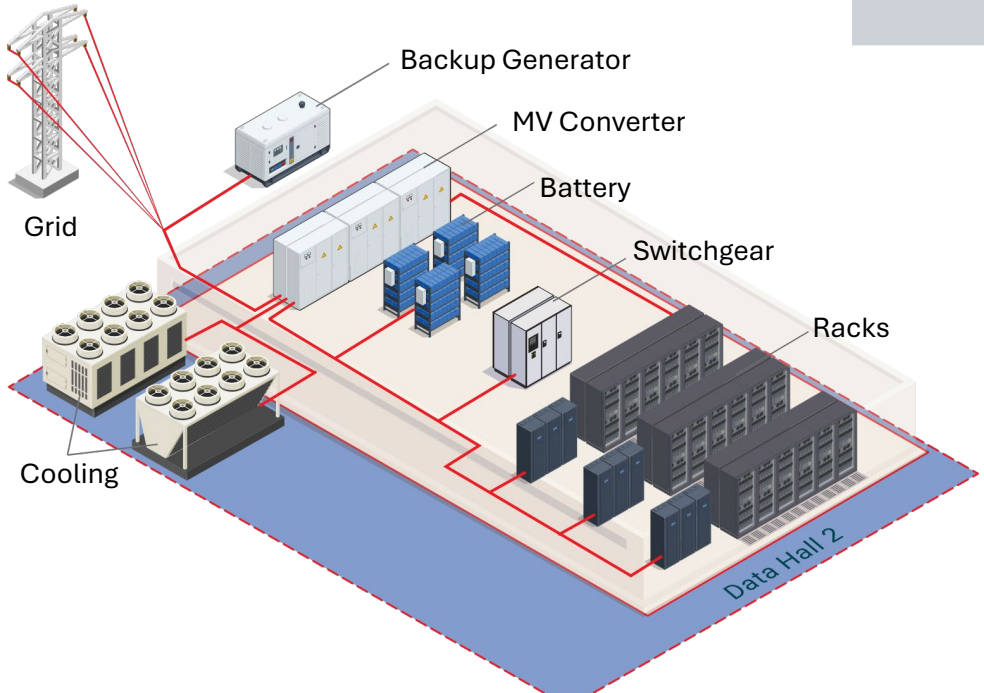
Metrics

- 30% loss reduction
- 20 % reduction in cost

Outlook

- Aligning DOE
- Engaging stakeholders
- Developing a white paper
- Internal stakeholders are very interested and engaged to support





Integrated Grid Systems : MVDC Technologies for a Reliable and Resilient Grid

Objectives

- MVDC power delivery systems at distribution scale
- MVDC based large load power infrastructure distribution- DC microgrids
- MVDC and LVDC interfaces for seamless integration of sources and loads

Challenges

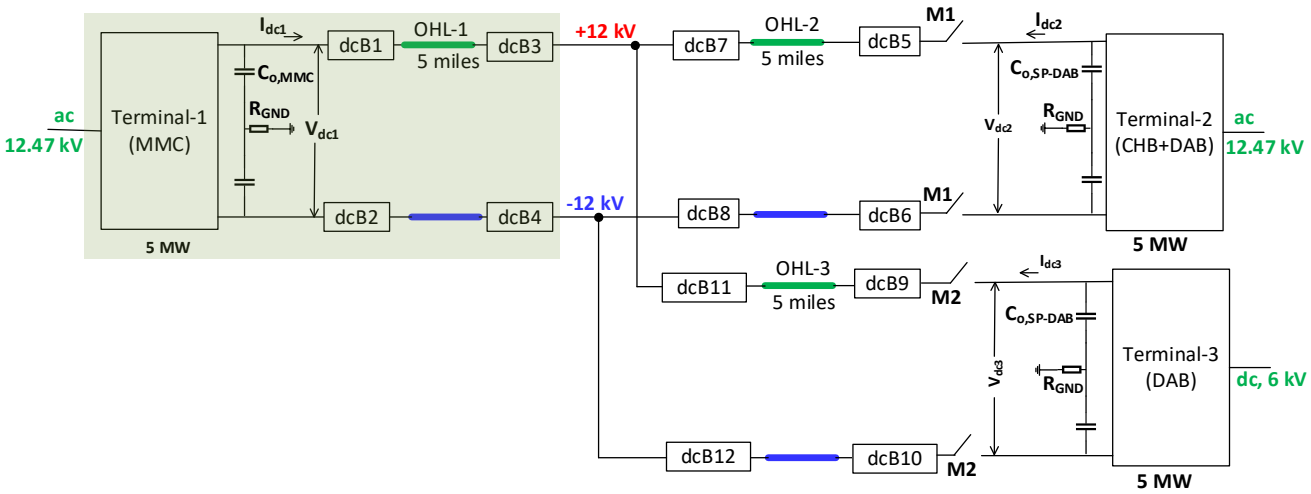
- Lack of DC protection devices
- Need advance controls and reliable PE systems

Metrics

- Solid state breakers < 50 us
- 98% peak efficiency

Outlook

- DOE funding the initial scope
- Utilities like southern interested for pilot
- Industry interested in partnering
- Identified testbeds a challenge



Integrated Grid Systems: Transformers Eco System R&D

Objectives

- Novel materials for GOES LPT
- Advanced high frequency isolation cores for distribution scale transformers
- Coreless transformers for grid edge infrastructure
- Remanufacturing of GOES transformer cores for secondary use of materials

Challenges

- Lack of manufacturing process for new concepts
- Reliability and standards
- Scaling of alternate alloys

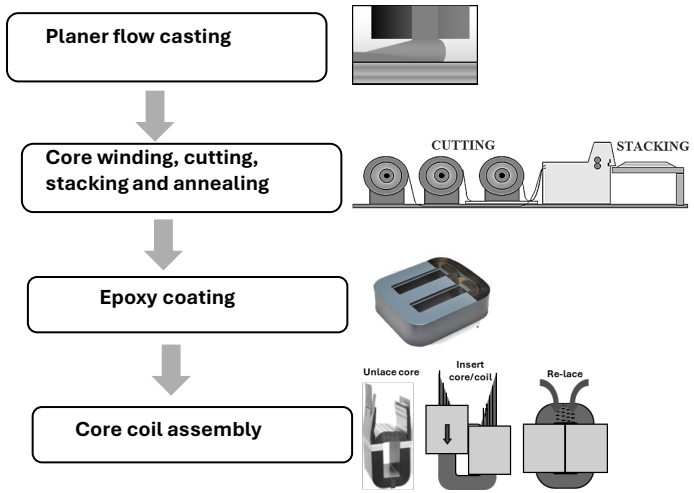
Metrics

- 95% efficiency at light loads and standby
- 30$/KVA

Outlook

Portfolio of projects funded by OE and CESER

- US manufacturers identified for partnership
- High risk and high reward for supply chain issues



High efficiency Amorphous transformer

Energy Storage Technologies

Objectives

- Solid state battery
- Sodium ion technology areas
- Flow batteries technologies-including advance systems
- Zinc-ion

Challenges

BOS system architecture

Long duration tech reliability

Metrics

- 4-8 hrs of operation
- < 200 $/kwhr
- 400 Wh/L and high power density

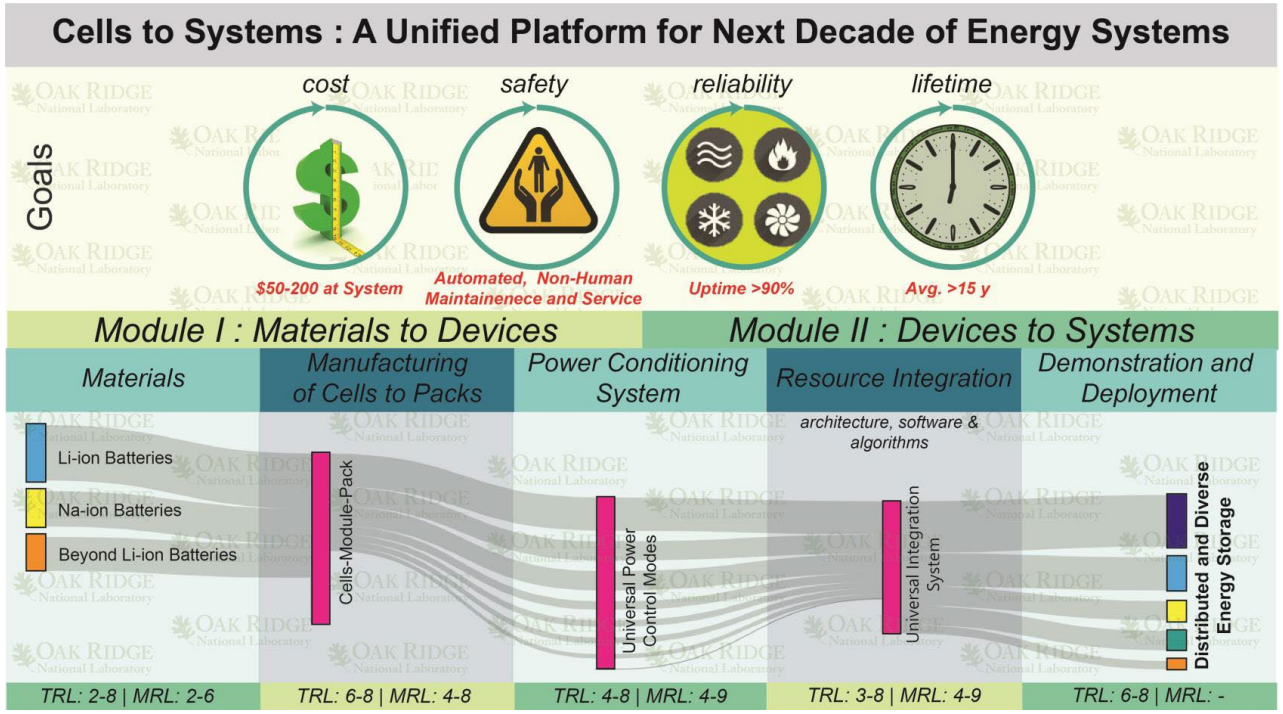
Outlook

Solid state battery technologies

Data HUB continues to grow

Storage based analytics and opportunity

Pilot demos



Grid Analytics

Objectives

- US Energy Sector Data Strategy Open Data Portal (Data catalog solution) with data governance for Energy sector:
  a. Energy Sector Data spaces - Federated interoperable and efficient data sharing platforms with data governance
  b. Interoperability Initiatives - Distribution Grid Modeling Publication, Green Button Initiatives, ODIN
  c. Privacy Enhancing Technologies and AI foundational models for the grid
- Advance Algorithms and AI Applications for Grid:
  a. Grid Planning and Optimization
  b. Grid Operations: Autonomous Grid Operations: operator assistance
  c. Reliability and Resilience: forecasting, detection and maintenance
  d. Generative AI models for decision support and predictive planning in power systems

Challenges

- ORNL is behind in analytics compared to industry
- Too many projects siloed and no co-herent vision

Metrics

- Autonomous grid operation level 2
- Develop ORNL's analytics framework and 1.0 version of GRASP

Outlook

Utilities continue to support the DATA

Data strategy will be a priority and well funded

AI based grid operations

Grid Resource Algorithm Synthesis Platform

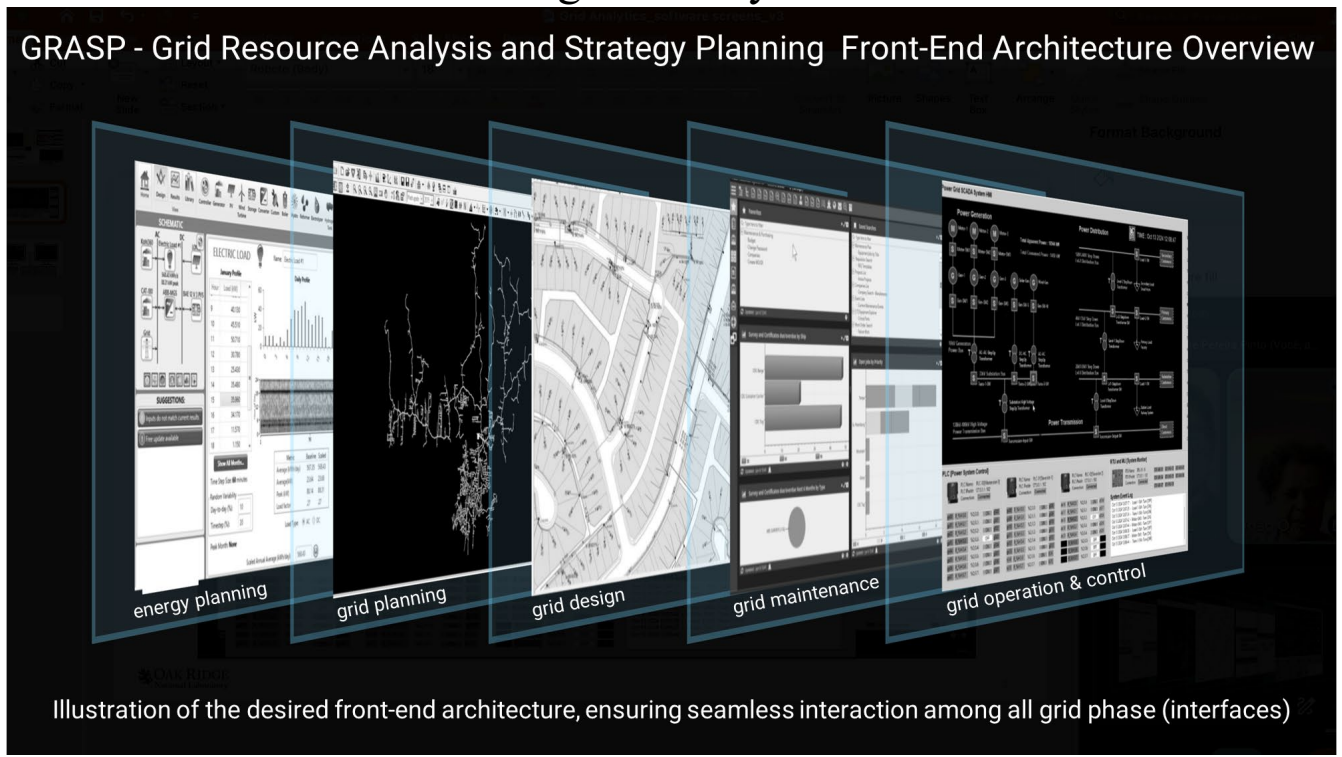


Illustration of the desired front-end architecture, ensuring seamless interaction among all grid phase (interfaces)

Grid Modeling

Objectives

- NAERM- Bulk grid and interdependency analysis
- EMT
  a. Develop US-based EMT simulation software.
  b. Grid components and systems models development
  c. New solvers and compute platforms for complex large scale simulations development
  d. Demonstration and validation of the software pilot with users that include system operators, utilities, OEMs

Challenges

Need more technical expertise and workforce to support this efforts

Developing skill set to establish the initial development of the tools

Metrics

EMT roadmap developed

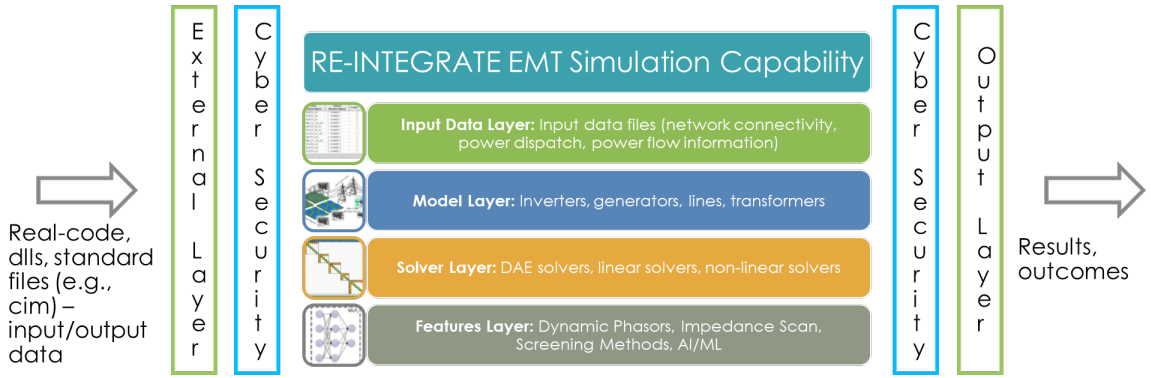
Unified EMT simulation framework design and initial version released

Outlook

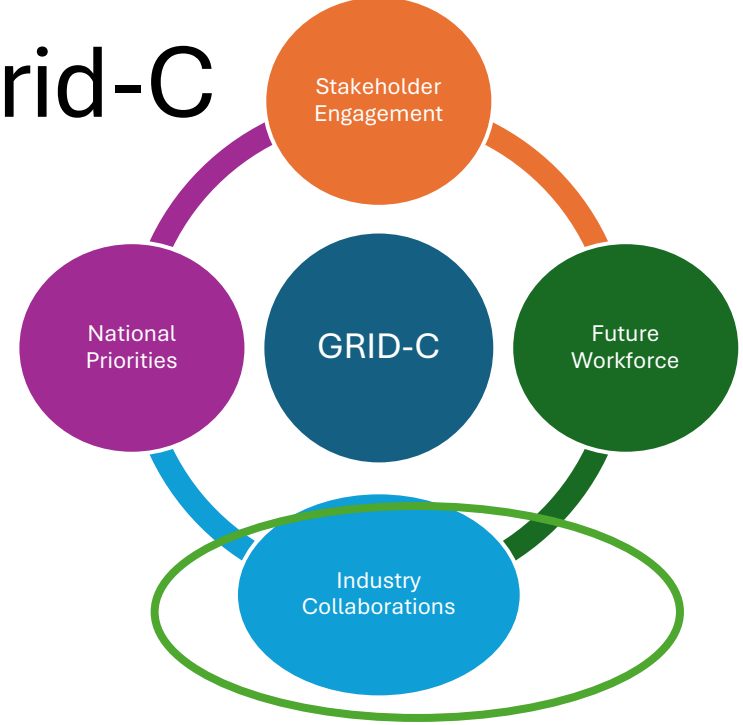
OE has funded the initial roadmap

Industry has been aligned and ready to support

Scalable Unified EMT Simulation Initiative [EMT Initiative]: RE-INTEGRATE



Technical Collaborations Program Grid-C



Program Intent

- **Provide open, affordable and convenient access to national lab infrastructure**, hosted resources, tools, and expertise to facilitate rapid development and adoption of new energy efficient technologies.

- **Collaborate with industry through cost shared projects** to investigate, improve, and scale process methodologies
  - to **reduce the risk and accelerate the development and deployment** of innovative energy efficient grid technologies
  - **de-risk adoption** of new energy efficient technologies

- Creation and preservation of **domestic ecosystem and creation of jobs** is a primary goal