GMLC 2.4.2 – Multiport HUB

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Project Summary

Increased number of PE-grid interfaces due to higher DER penetration and load evolution will mandate a change in the design and architecture of the interfaces.

Challenges:

Multiple power converters on the grid

- ✓ communicate, control, and coordinate

Multiple vendors with one-off designs, proprietary software and communications interfaces

- ✓ Interoperability issues due to lack of standards for communication & interfacing

Lack of autonomous operating capability: centralized control is needed

Critical Needs:

Automation of energy flow between multiple sources and loads with real-time optimization

Increase in grid reliability and resilience for advanced de-centralized grid control architecture

Increase in grid security:

- ✓Minimizing the number of DER nodes on the grid
- ✓Single point of communication with distribution management systems and other utility management systems

Interoperable/Vendor agnostic

- ✓Modular and scalable agent-based software platform with real-time dynamic control of grid

The Numbers

- DOE PROGRAM OFFICE:
  OE – Transformer Resilience and Advanced Components (TRAC)
- FUNDING OPPORTUNITY:
  Grid Modernization Lab Call 2019
- LOCATION:
  Oak Ridge, TN
- PROJECT TERM:
  02/01/2020 to 06/01/2022
- PROJECT STATUS:
  Completed
- AWARD AMOUNT (DOE CONTRIBUTION):
  $2.3M
- AWARDEE CONTRIBUTION (COST SHARE):
  $700k
- PARTNERS:
  Semikron, NCSU, Southern Company, NREL, PNNL

Technical Approach

Simulation

- Features of Hub/Node
- Use Case Development and Evaluation
- Basic Functionality Defined
- PE Control Concepts

STAGE 1: FY 20

CHIL

- Communication Layers and Architecture
- DSP Programming
- Optimization and Control Layers

STAGE 2: FY 21

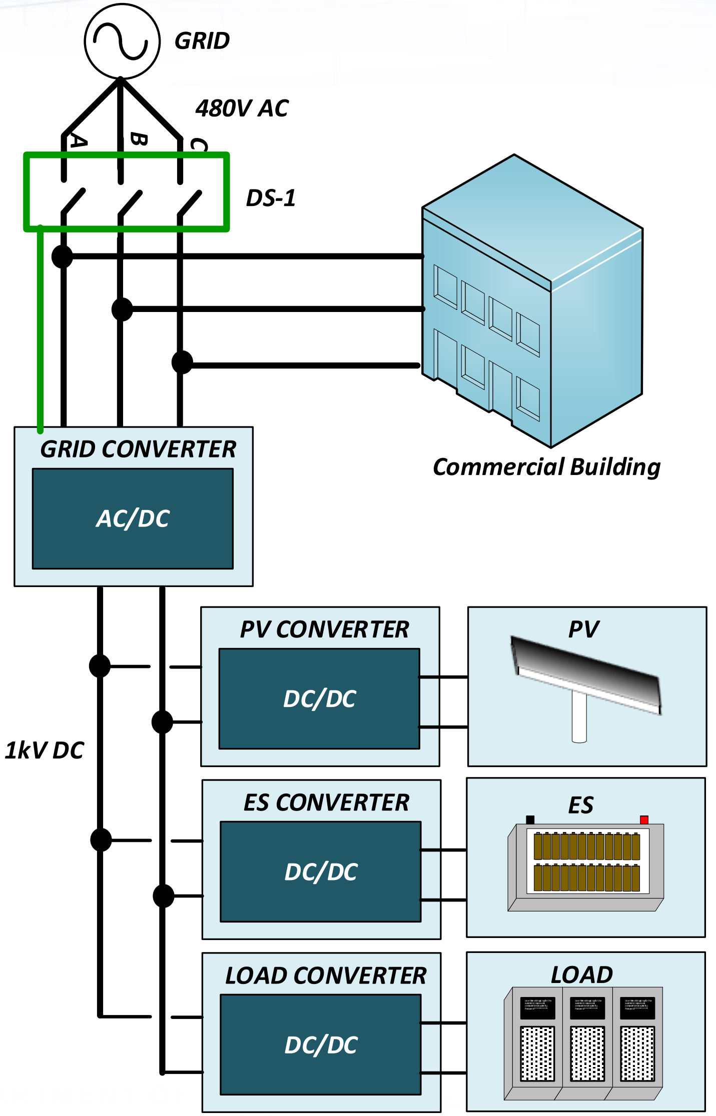
Hardware

- ORNL Hardware Development
- Hardware Testbed Development
- ORNL Hardware Demonstration
- Vendor/University Hardware

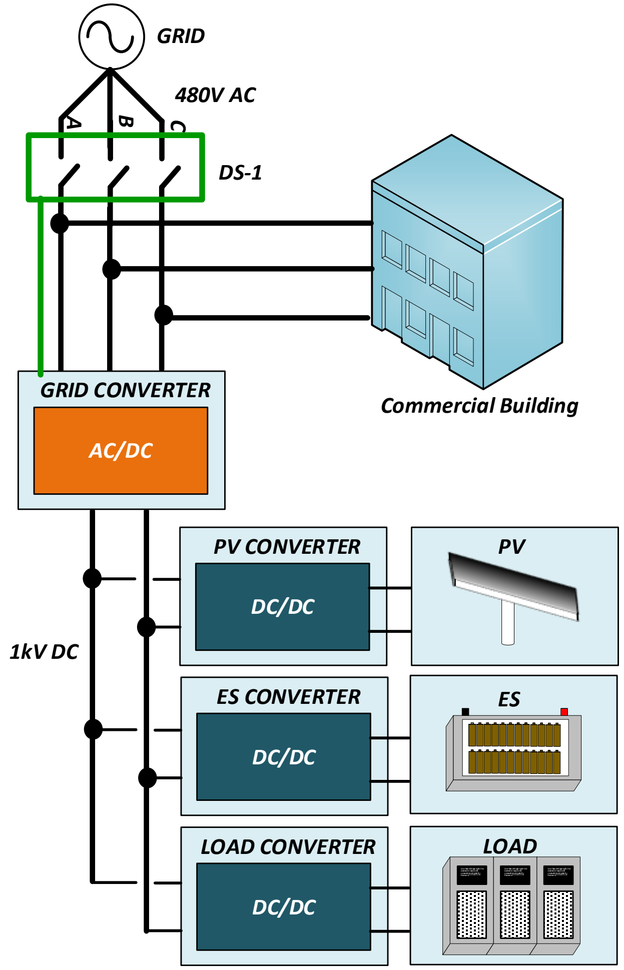
STAGE 3: FY 22

Accomplishments: Use Case and Simulation (1/3)

- Features / Use Case:
  - A system of power electronic converters, communication, and controls to support commercial building:
    - *Renewable and energy storage integration*
    - *Increased reliability and resilience (particularly in the case of micro data centers)*
    - *Economic optimization for utility cost reduction and also driven by higher order systems*
  - Operates in parallel with the grid increasing efficiency

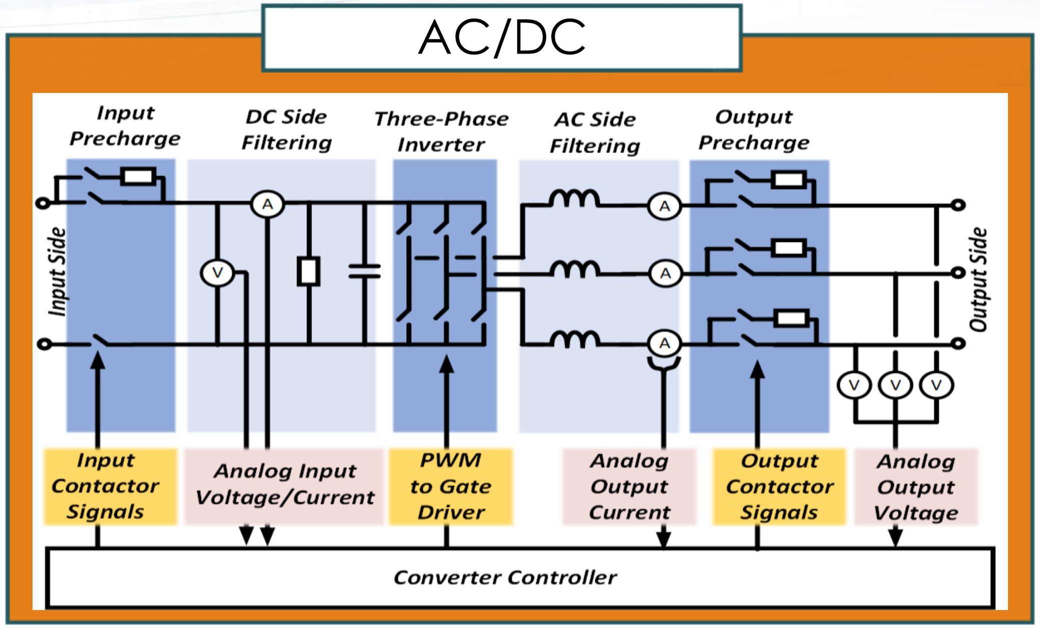


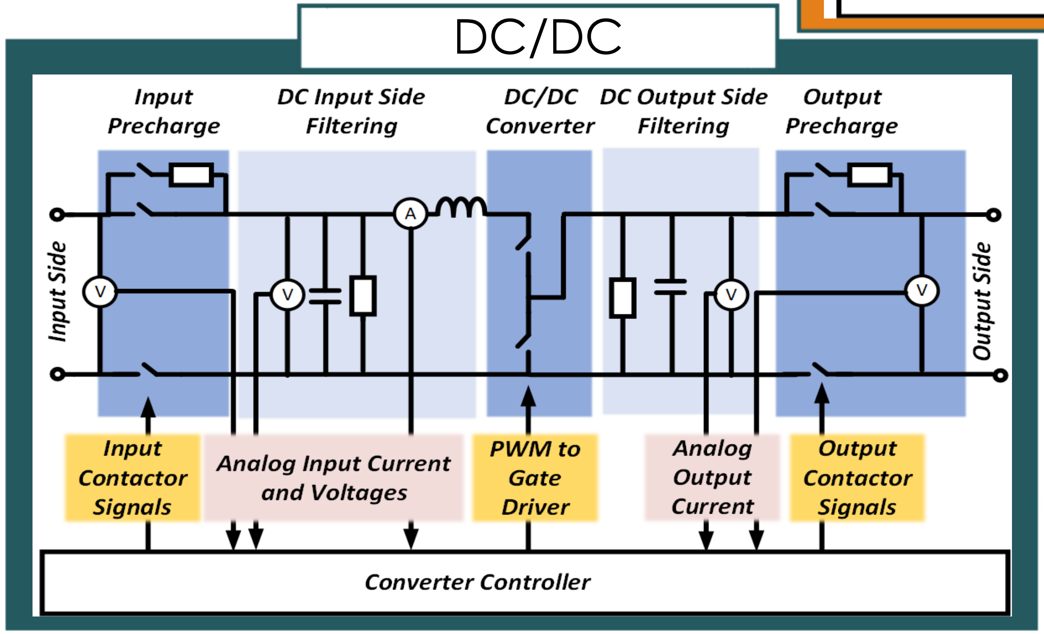
Accomplishments: Use Case and Simulation (2/3)



***Objective*: Select and develop converter models to support use case**

Traditional AC/DC topology with L filters





DC/DC buck-boost converter

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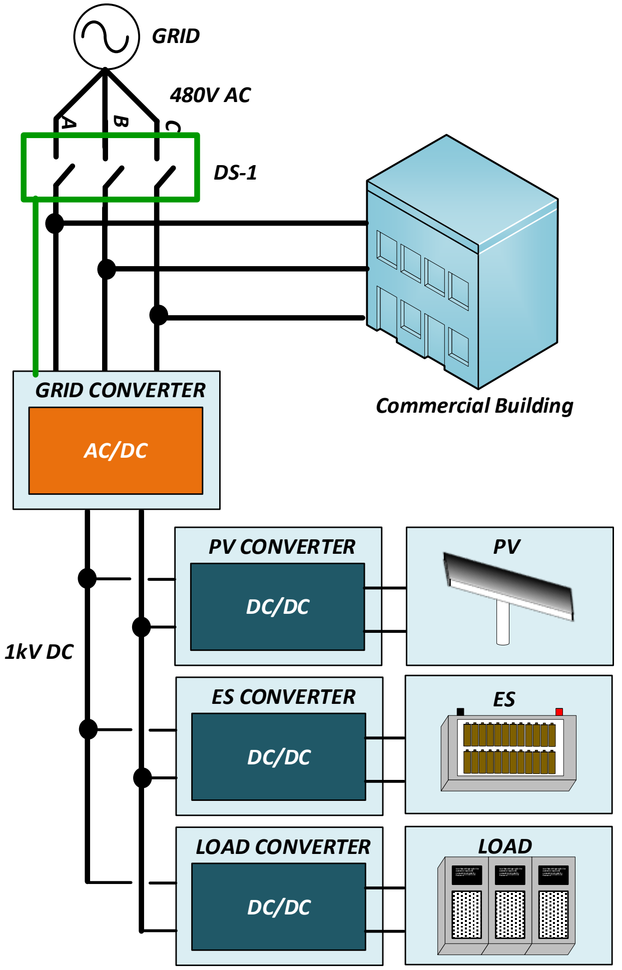
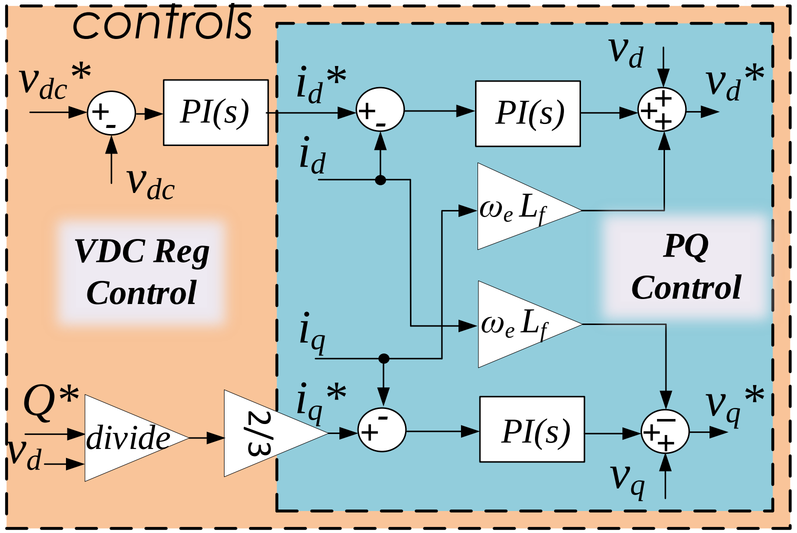
Accomplishments: Use Case and Simulation (3/3)



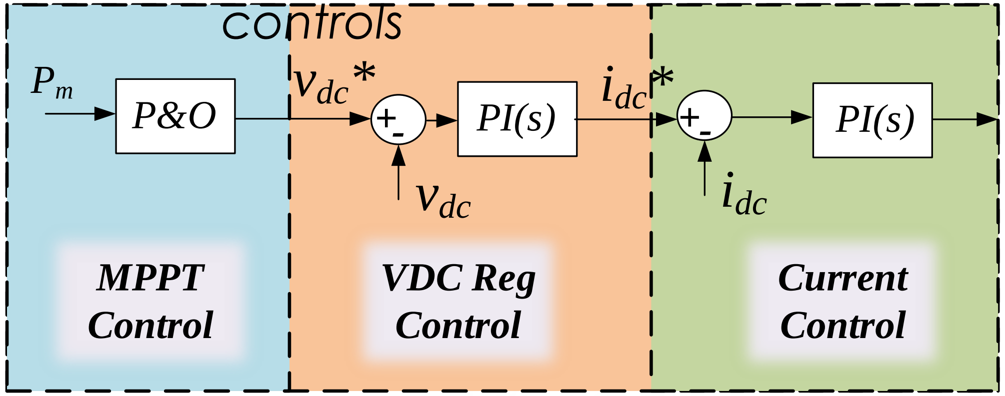
***Objective*: Develop converter controls to support use case**

System Configuration	DSP Control Option	
	Input	Output
Grid Converter (DC/AC)	Vdcreg	Grid Following Q, Grid Forming (V/F)
PV Converter (DC/DC)	MPPT	
ES Converter (DC/DC)		P, Vdcreg
Load Converter (DC/DC)	Vdcreg	

AC/DC fundamental controls

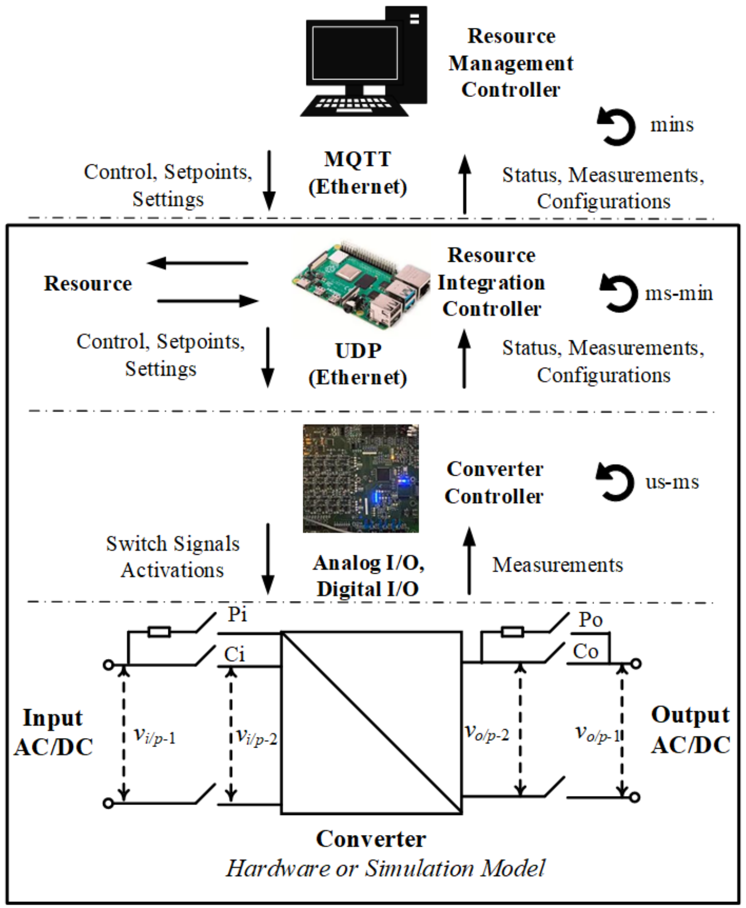


DC/DC fundamental controls

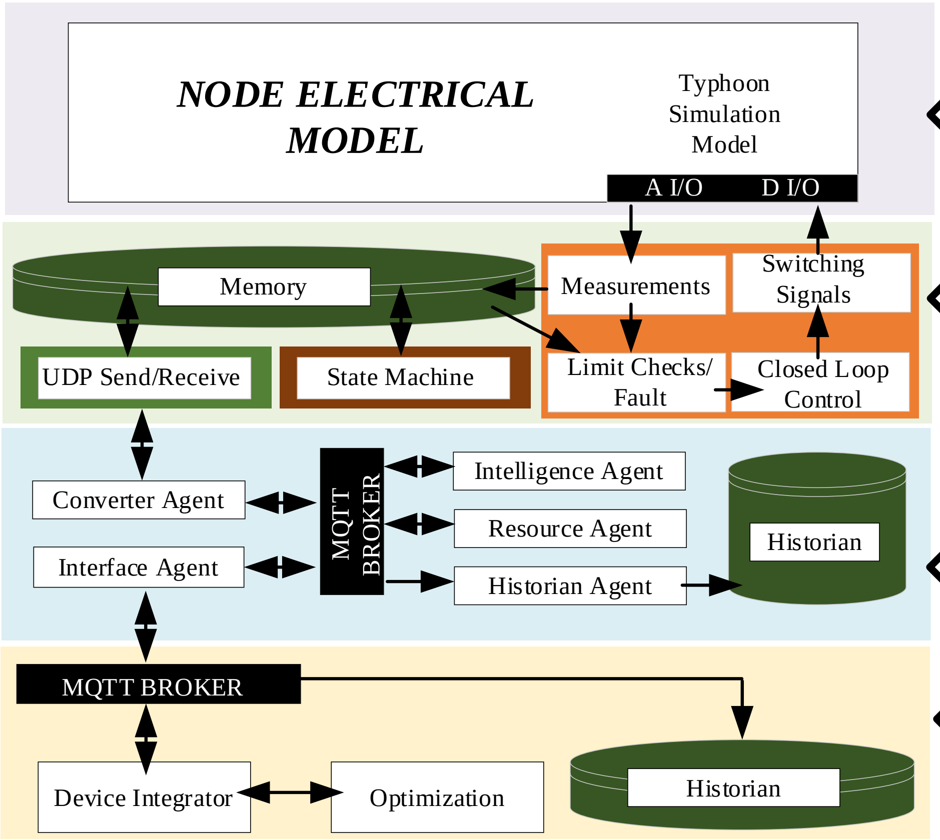


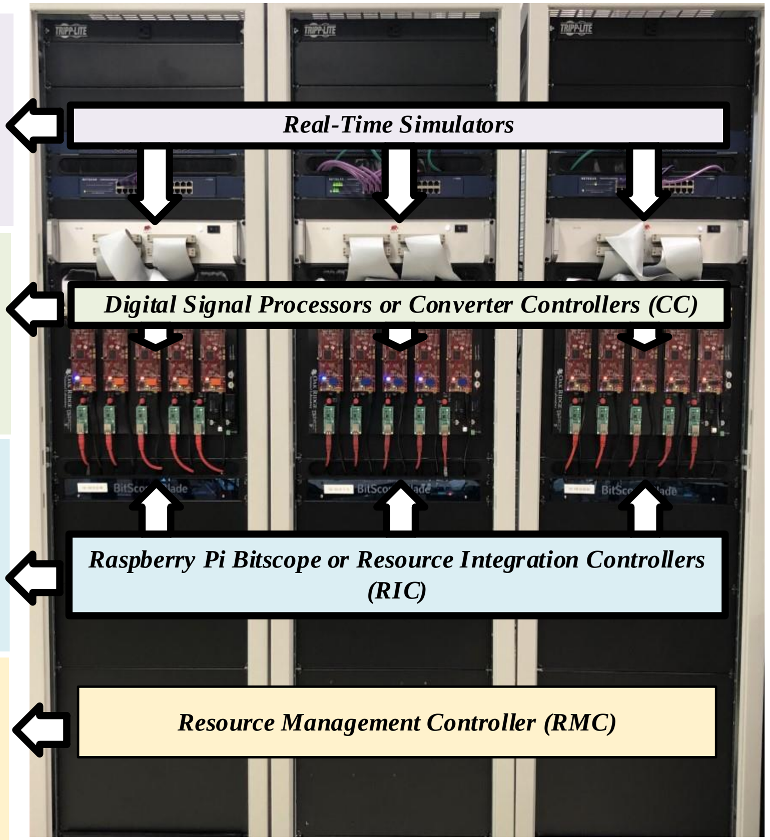
Accomplishments: Controller Hardware in the Loop (1/3)

***Objective*: Develop communications, software, and controllers to support use case.**



Power Electrics Integrated Resource





Accomplishments: Controller Hardware in the Loop (2/3)

***Objective:** Develop optimization formulation and integrate with platform. Initially focus on economical signal.*

Objective Function

Objective = min($\sum \gamma_t^b P_t^{ccC} - \gamma_t^s P_t^{ccD}$ $+ \sum P_t^{ccAux}$ $+ \sum SOC_t^{bAux}$

Economics | GridPCC Limit | ES Capacity Limit

Energy Storage Model

$SOC_{t+1}^b = SOC_t^b + (P_t^{cb}\eta - P_t^{db}/\eta - P_t^{loss})\Delta t / E_b$ Energy Model

$0 \leq P_t^{db} \leq P_{MAX}^{db} b_t^{db}$ $\quad 0 \leq P_t^{cb} \leq P_{MAX}^{cb} b_t^{cb}$

$b_t^{cb} + b_t^{db} \leq 1$ Power Limits

$SOC_t^{bAux} \geq \begin{Bmatrix} 0 \\ SOC_t^b - SOC_{MAX}^b \\ SOC_{MIN}^b - SOC_t^b \end{Bmatrix}$ Energy Limits

Pgrid Converter

$0 \leq P_t^{gcD} \leq P_{MAX}^{gcD} b_t^{gcD}$ $\quad 0 \leq P_t^{gcC} \leq P_{MAX}^{gcC} b_t^{gcC}$

$b_t^{gcC} + b_t^{gcD} \leq 1$ Power Limits

PV and Load

$0 \leq P_t^{pv} \leq P_t^{pvforc}$ $\quad 0 \leq P_t^{load} \leq P_t^{loadforc}$

PCC

$P_t^{ccAux} \geq \begin{Bmatrix} 0 \\ P_t^{ccC} - P_{MAX}^{Ccc} \\ P_t^{ccD} - P_{MAX}^{Dcc} \end{Bmatrix}$ $\quad 0 \leq P_t^{ccC} \leq 10^{10} b_t^{ccC}$ $\quad 0 \leq P_t^{ccD} \leq 10^{10} b_t^{ccD}$ $\quad b_t^{ccC} + b_t^{ccD} \leq 1$

DC Bus Model

$P_t^{gcC} - P_t^{gcD} == P_t^{pv} - P_t^{load} - P_t^{cb} + P_t^{db}$

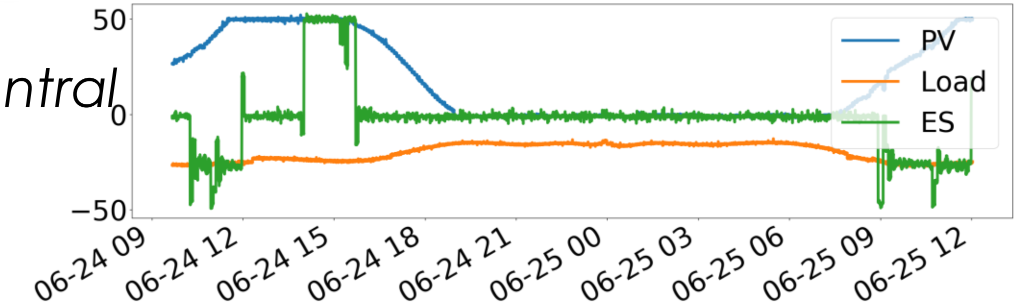
AC Bus Model

$P_t^{ccC} - P_t^{ccD} = P_t^{gcC} - P_t^{gcD}$

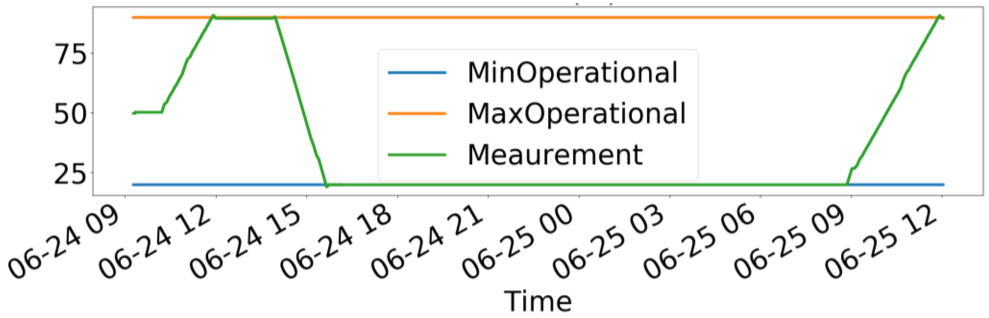
Accomplishments: Controller Hardware in the Loop(3/3)

***Objective:* Validate framework is working in CHIL**

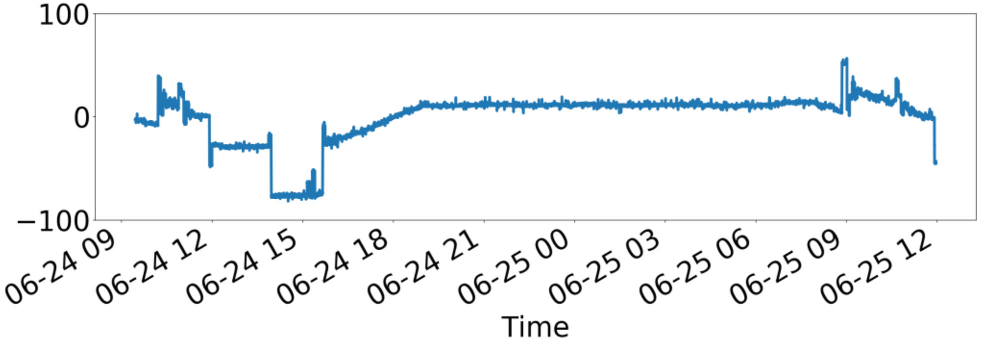
Power recordings from central controller perspective

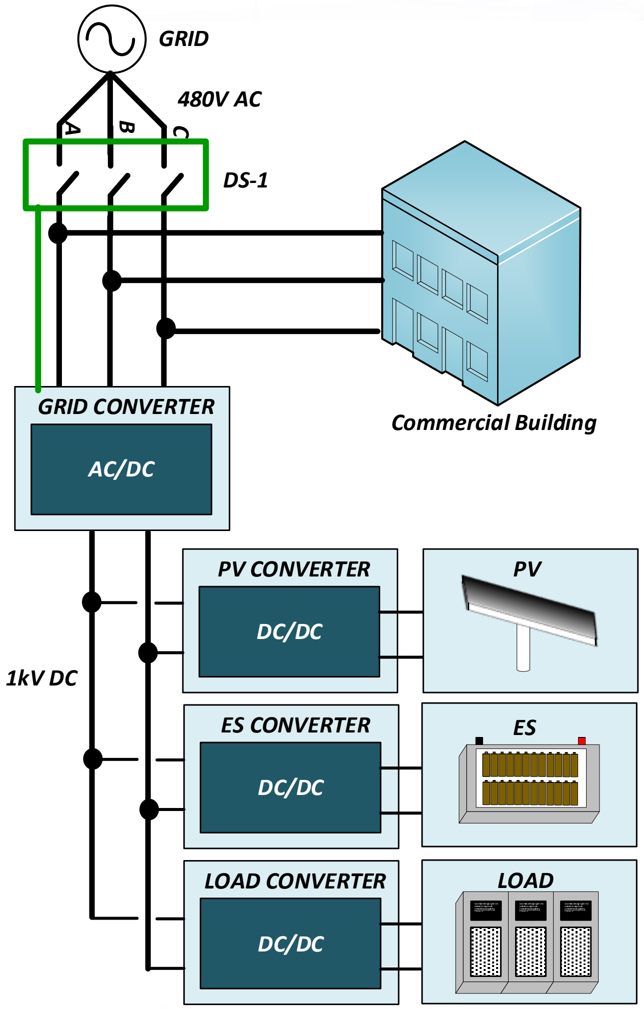


Energy storage state of charge (CHIL model)



AC/DC Grid Converter observed measurements

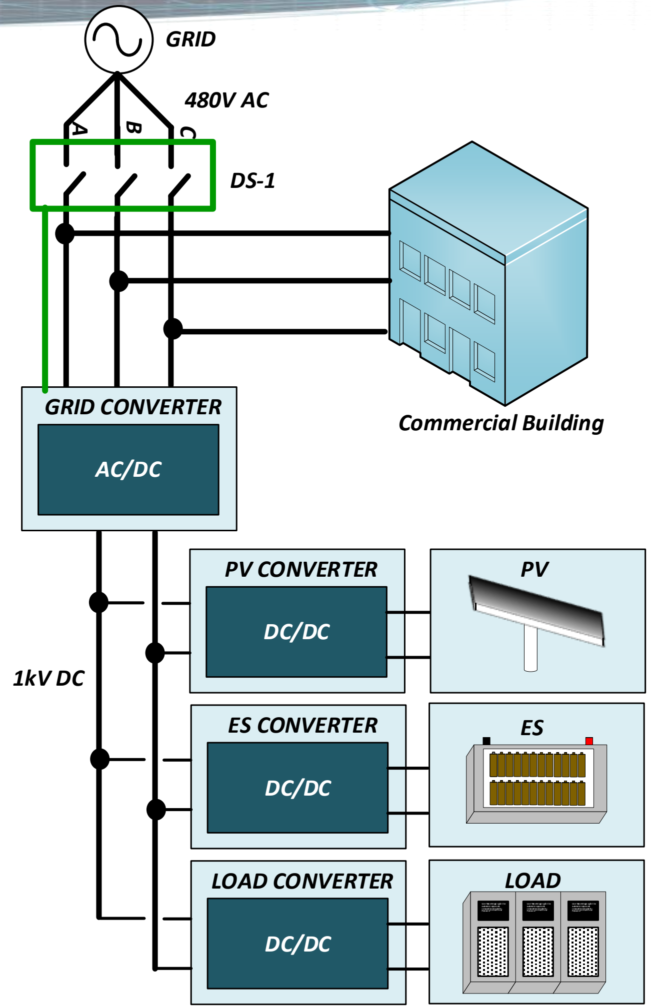


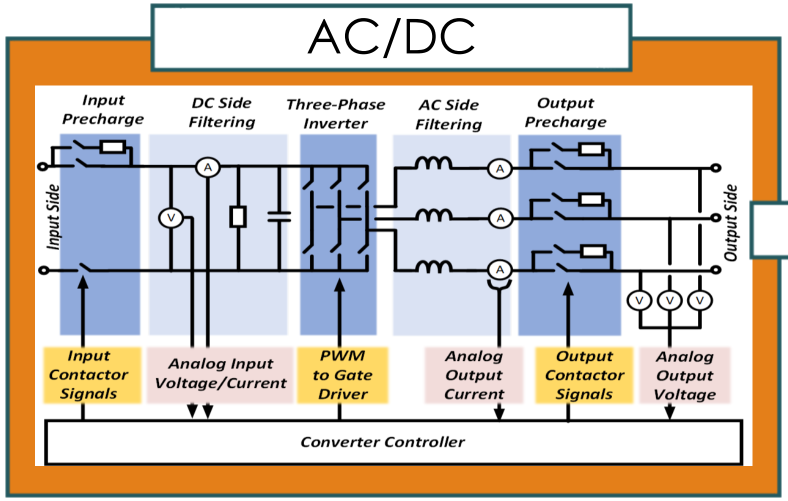


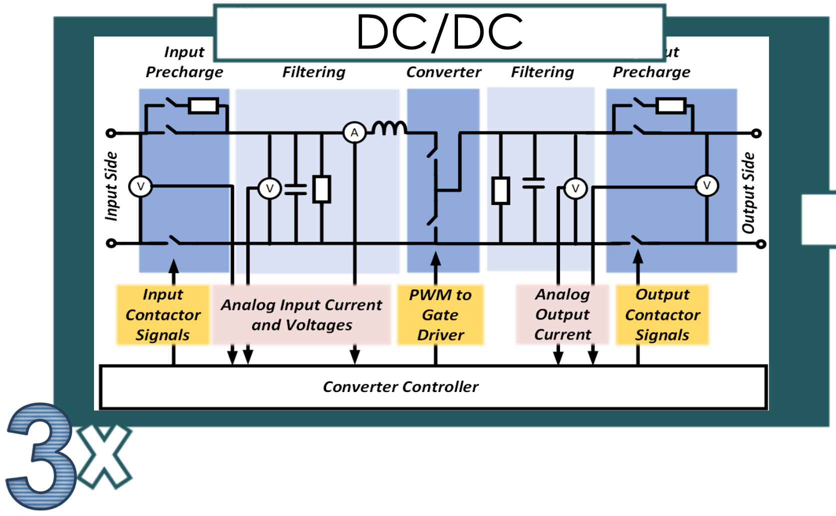
REF: M. Starke, B. Xiao and M. Chinthavali, "A Low Voltage DC Power Electronic Hub to Support Buildings," 2021 IEEE Fourth International Conference on DC Microgrids (ICDCM), 2021, pp. 1-8.

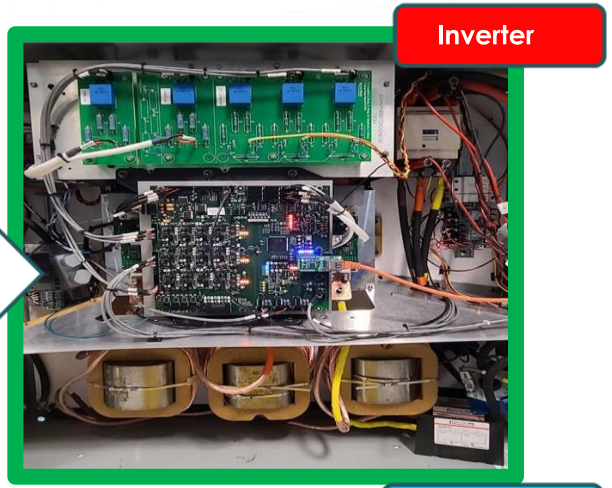
Accomplishments: Hardware Implementations (1/6)

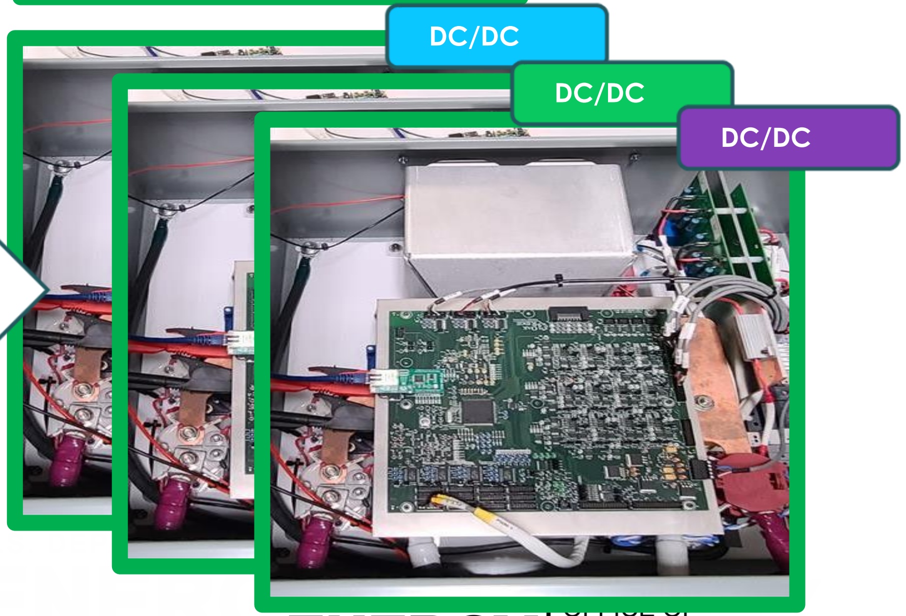
Objective: ***Construct appropriate hardware for validation***











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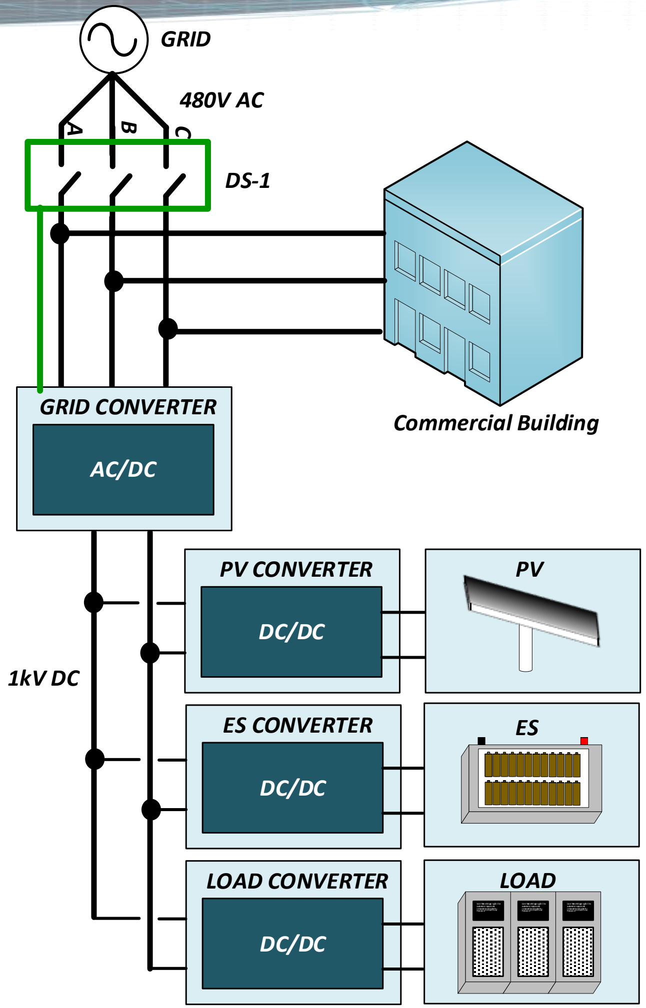
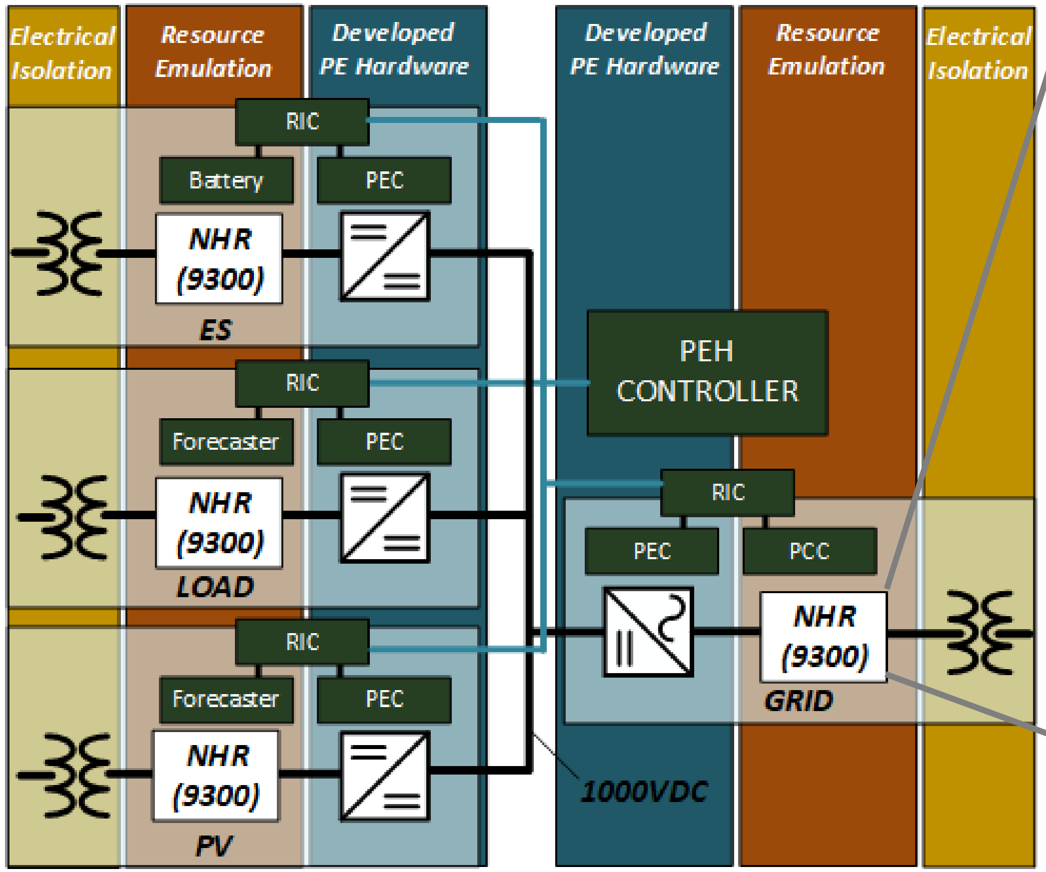
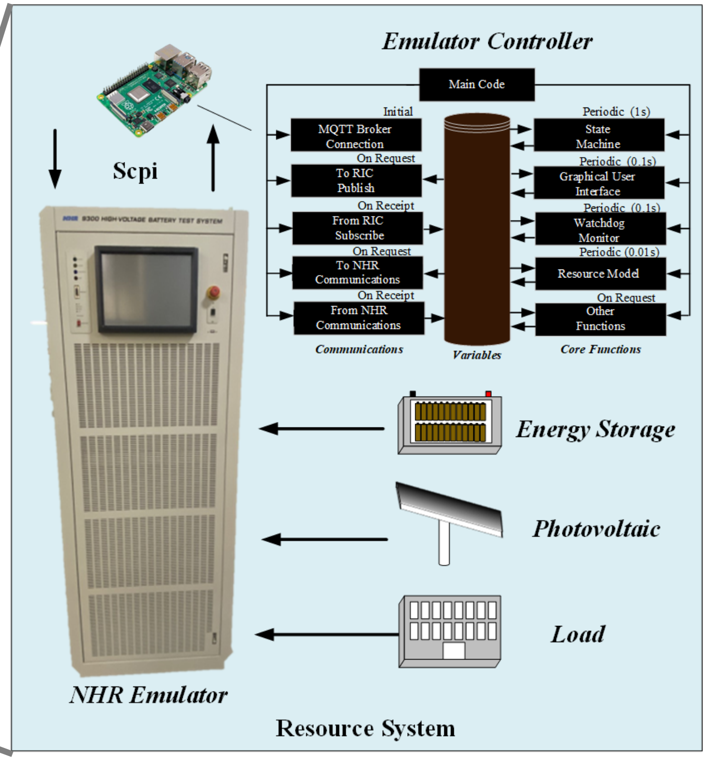
Accomplishments: Hardware Implementations (2/6)

***Objective:* Construction of appropriate testbed for validation.**





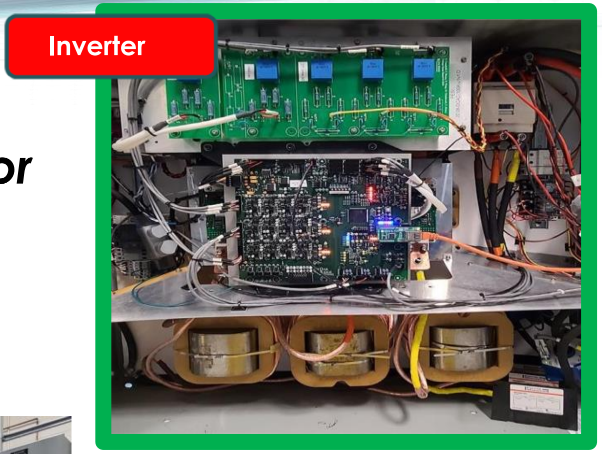


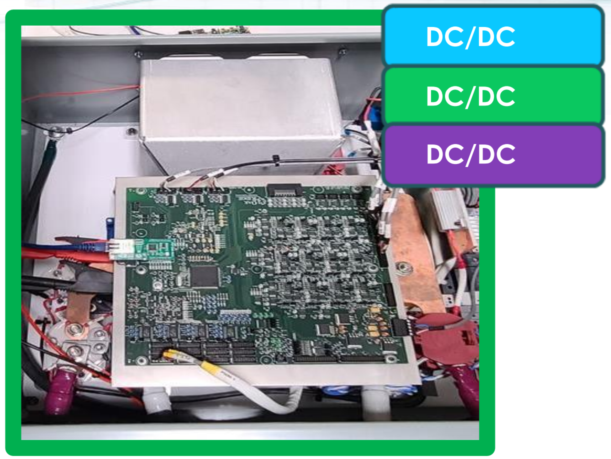
Emulation

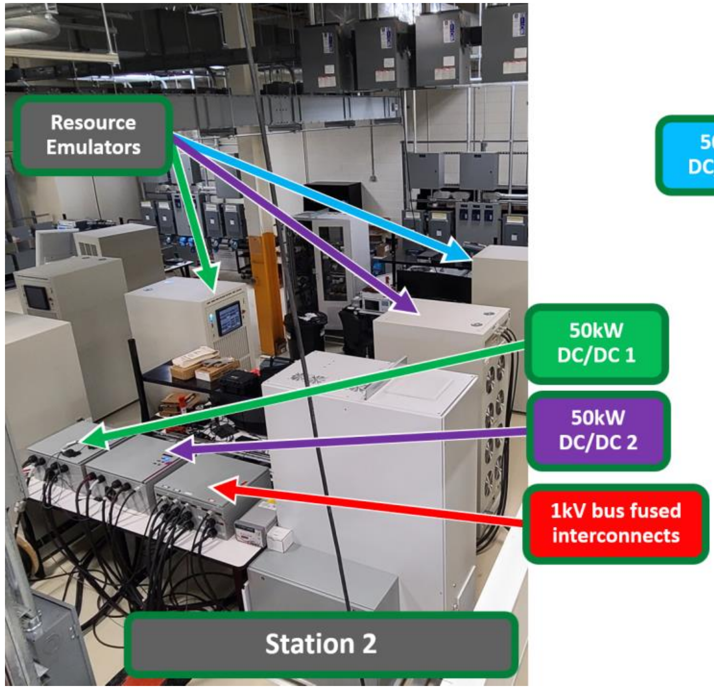
REF: B. Dean, M. Starke, S. Campbell and M. Chinthavali, "A framework for evaluating power electronic systems for grid integration," 2022 IEEE 7th Southern Power Electronics Conference (SPEC), Nadi, Fiji, 2022, pp. 1-6.

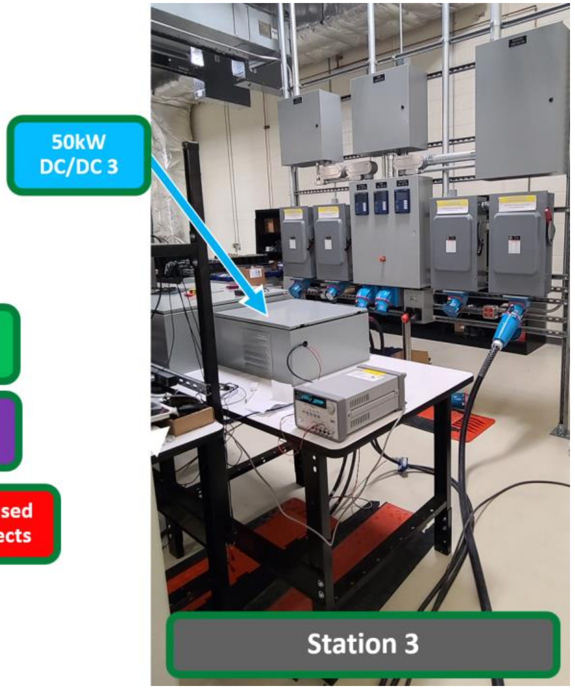
Accomplishments: Hardware Implementations (3/6)

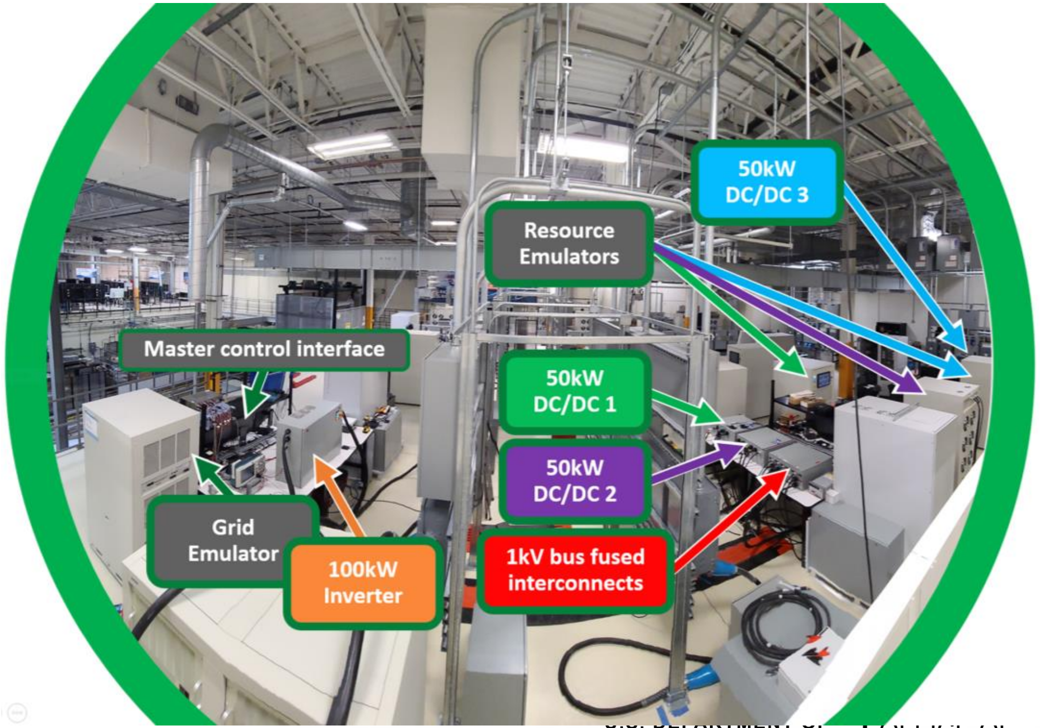
Objective: ***Construction of appropriate testbed for validation.***









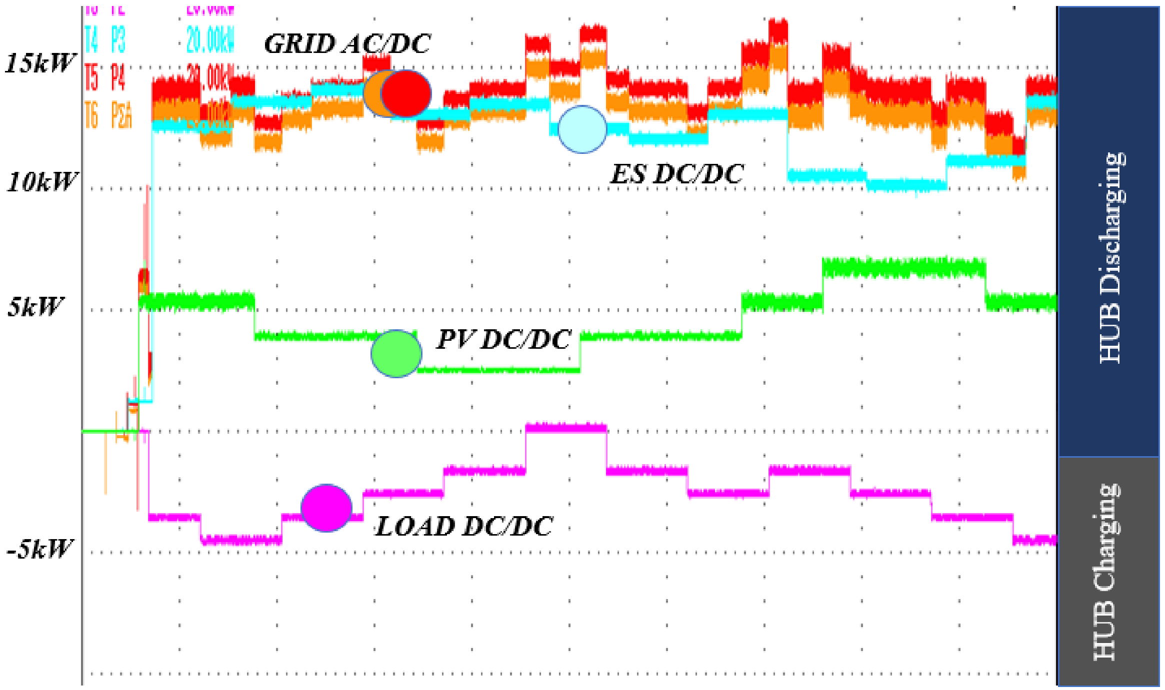


Accomplishments: Hardware Implementations (4/6)

<u>Objective:</u> Validate overall construct in hardware.

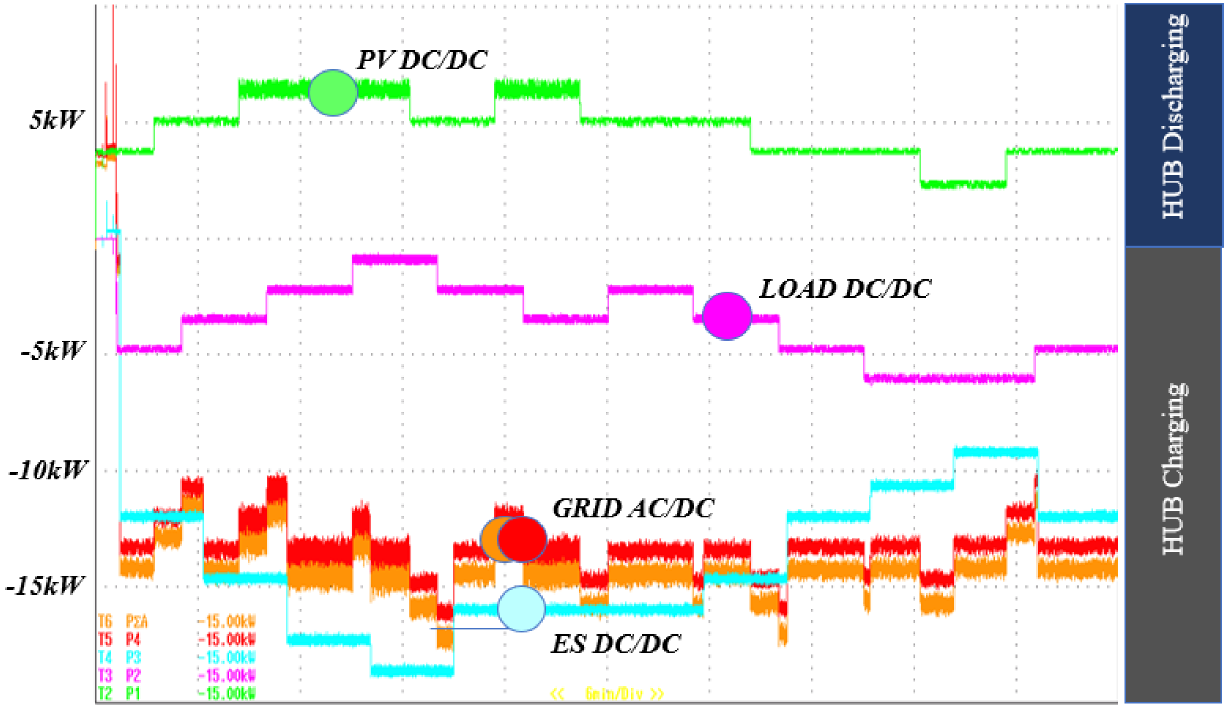
Objective Function

Objective = min($\sum WPCC \times UAUXt$)



Targeting Constraints

$$U_{AUX}^{t} \geq P_T^{t} - P_L - P_{PEHC}^{t} + P_{PEHD}^{t}$$
$$U_{AUX}^{t} \geq -P_T^{t} - P_L + P_{PEHC}^{t} - P_{PEHD}^{t}$$
$$U_{AUX}^{t} \geq 0$$

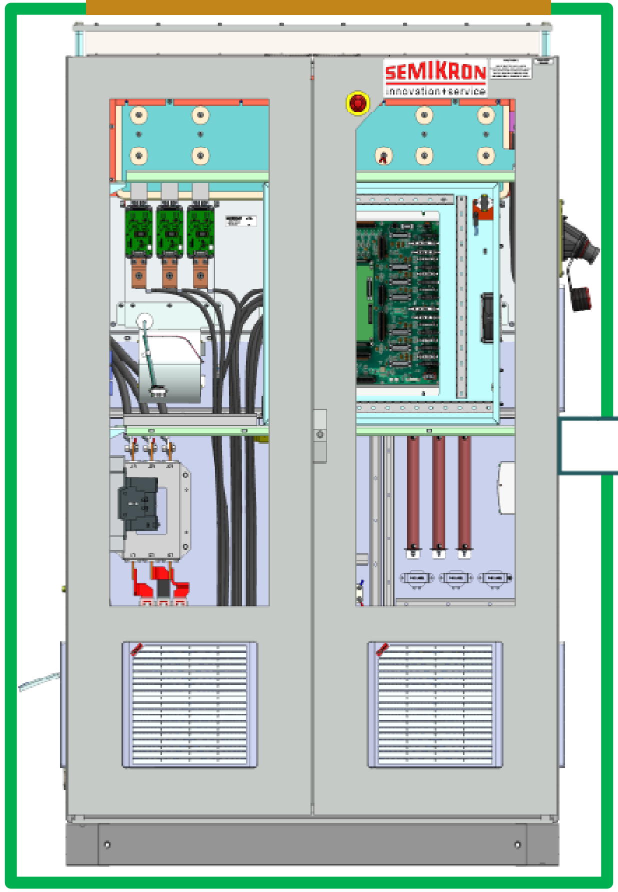


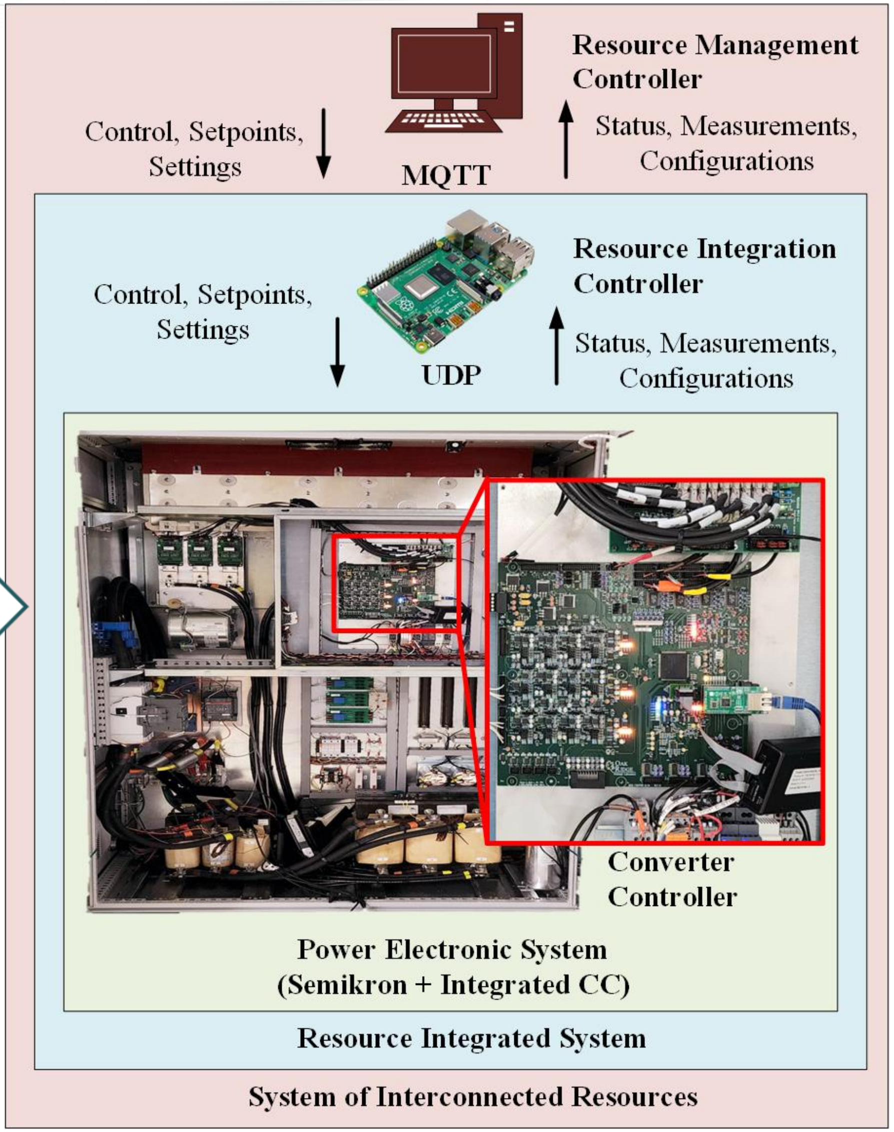
REF: M. Starke, S. Campbell, M. Chinthavali and B. Dean, "A 1kV, 480V Power Electronics Hub for DER Integration in Commercial Buildings," 2022 IEEE Energy Conversion Congress and Exposition (ECCE), 2022, pp. 1-7.

Accomplishments: Hardware Implementations (5/6)

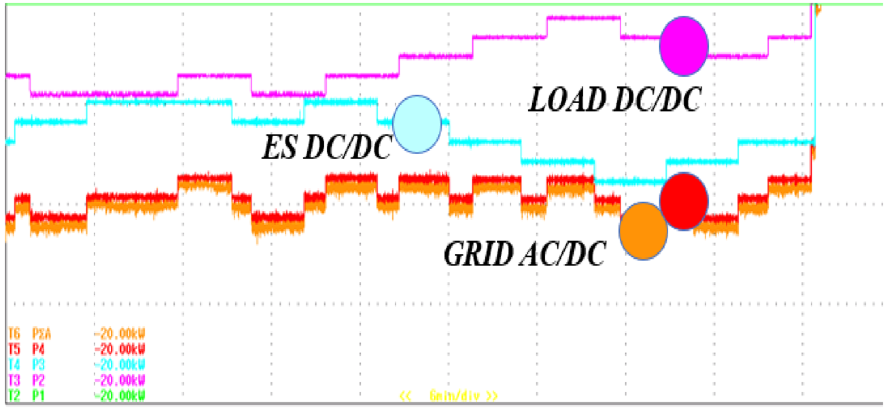
***Objective:* Vendor hardware integration and demo**

Semikron Developed 250 kW DC-AC





- Partner/Vendor Converter with Power Stage
- Integration Needs:
  - Gate Drivers
  - Converter Controls and Controller
  - Resource Integration
- Testing Needs
  - Voltage Regulation Output Controls Under Dynamic Loading
  - Integration and demonstration of system level control and coordination.



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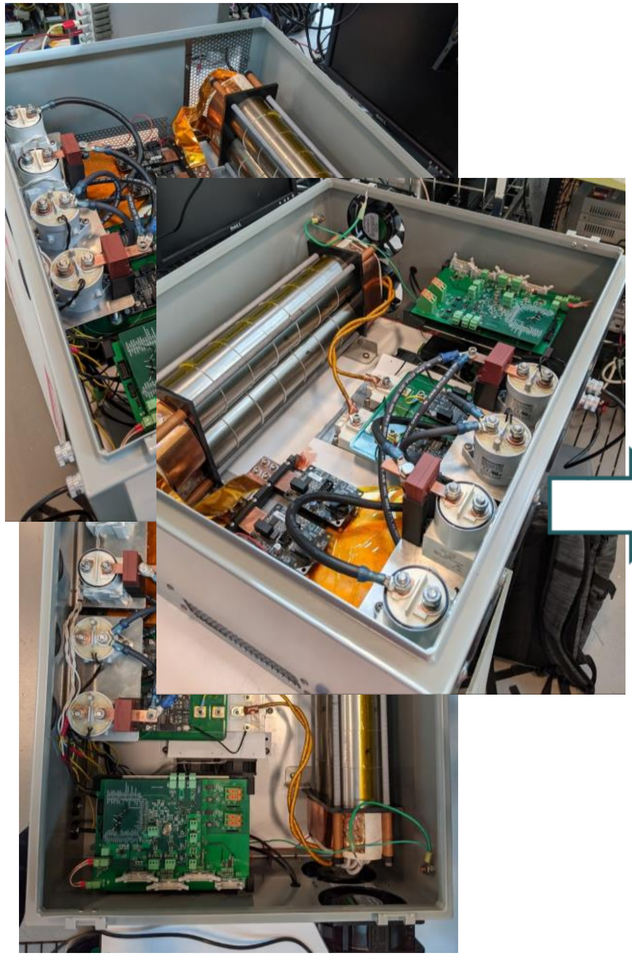
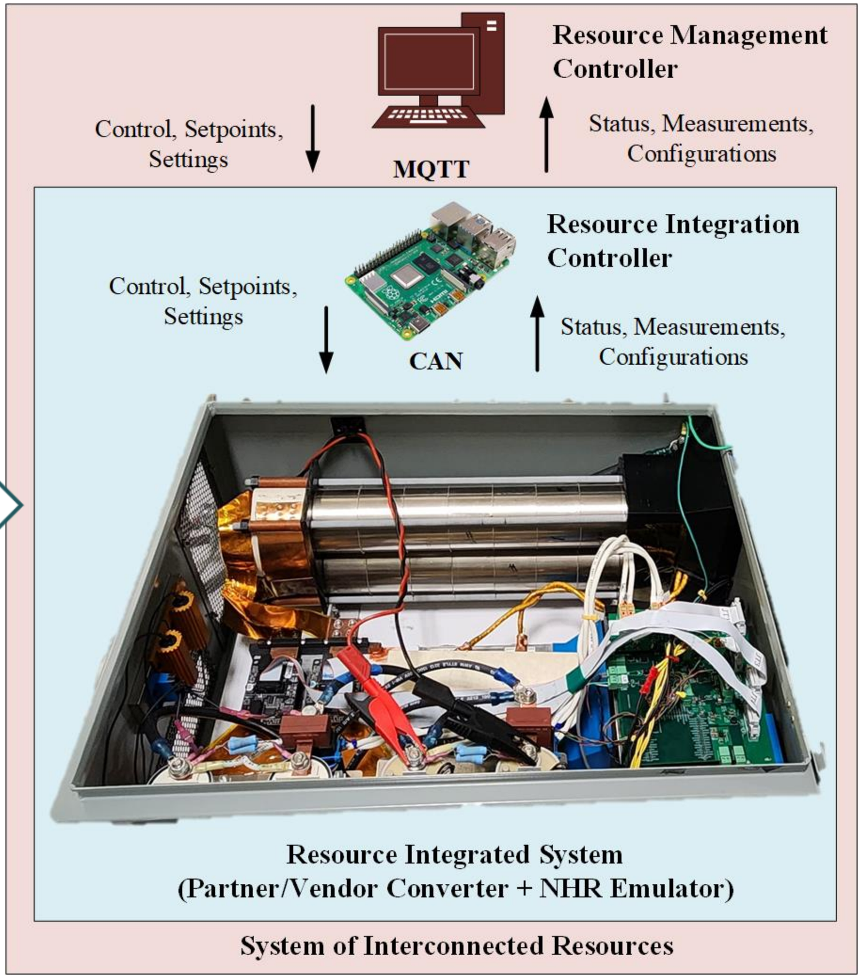
Accomplishments: Hardware Implementations (6/6)

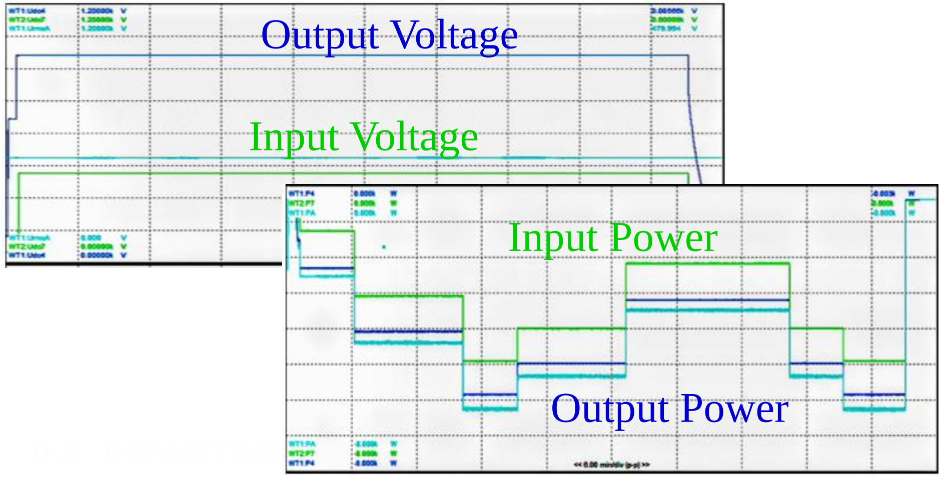
NCSU 50kW SiC Dual Active Bridge DC-DC





Objective: ***University hardware integration and demo***

- Partner/Vendor Converter with Integrated Converter Controller.
- Integration Needs:
  - Resource Integration
  - State Machine Translation
  - Communication Protocol Adoption and Translation
- Testing Needs
  - Voltage Regulation Controls Under Dynamic Loading (Input Side or 400VDC Side)



Impact/Commercialization

Summary
- Baseline LV-HUB Completed
- Hardware system testbed and automated software for test bed completed
- NCSU DC-DC Hardware evaluated and integration into LV-HUB platform
- Semikron DC-AC 250 Kw Hardware evaluated and integration into LV-HUB platform

Products
- Demonstrated plug-and play concept with two different partners- commercial and academic
- Developed a new product for 480 V in partnership with Semikron

<u>Publications</u>:

- M. Starke, B. Xiao and M. Chinthavali, "A Low Voltage DC Power Electronic Hub to Support Buildings," 2021 IEEE Fourth International Conference on DC Microgrids (ICDCM), 2021, pp. 1-8.
- M. Starke, S. Campbell, M. Chinthavali and B. Dean, "A 1kV, 480V Power Electronics Hub for DER Integration in Commercial Buildings," 2022 IEEE Energy Conversion Congress and Exposition (ECCE), 2022, pp. 1-7.
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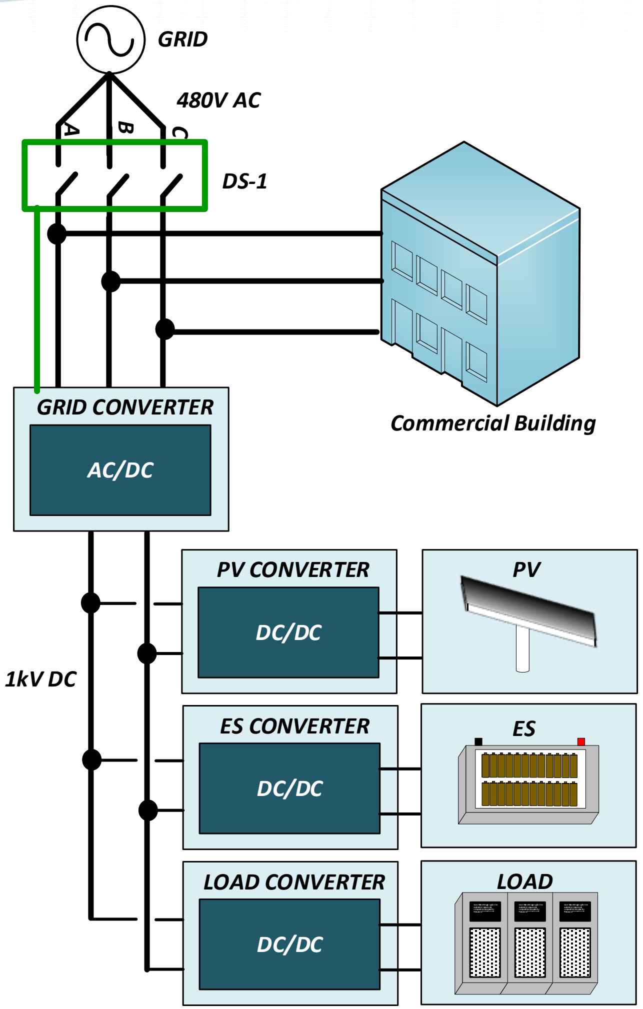
Plans:
- Work with Utility partner Southern Company to transition for field demo
- Engage with vendor partners for future demonstration projects

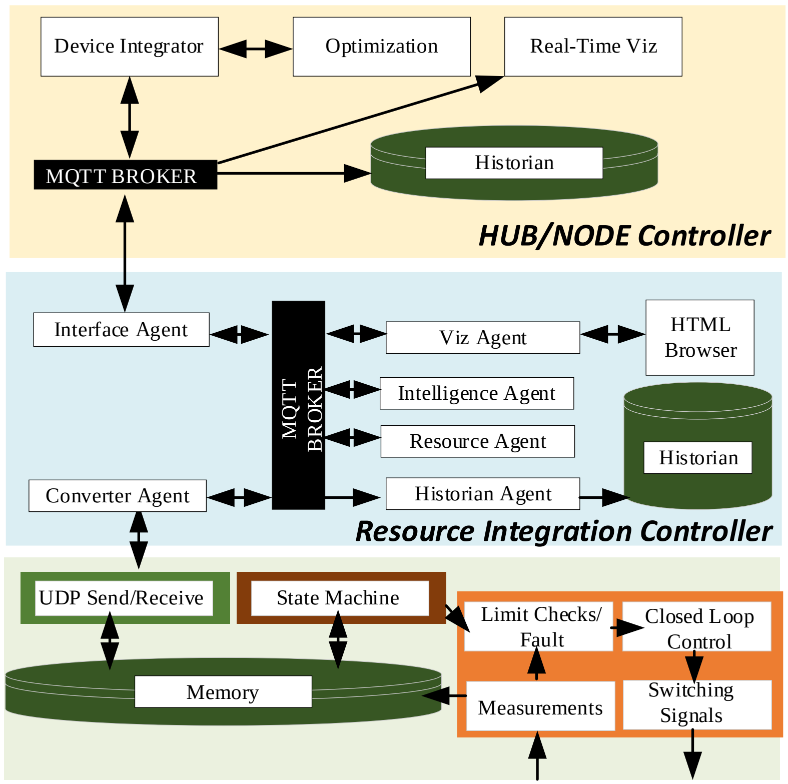
Future Work (Opportunities)

Expand to demonstration phase



Expand architecture

Higher hierarchical system development



Increasing capability and intelligence

THANK YOU

This project is supported by the U.S. Department of Energy (DOE) Office of Electricity's Transformer Resilience and Advanced Components (TRAC) program. It is led by Andre Pereira, TRAC program manager.

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