Power Electronics Development for Energy Storage at ORNL

2022 DOE OFFICE OF ELECTRICITY ENERGY STORAGE PROGRAM ANNUAL PEER REVIEW

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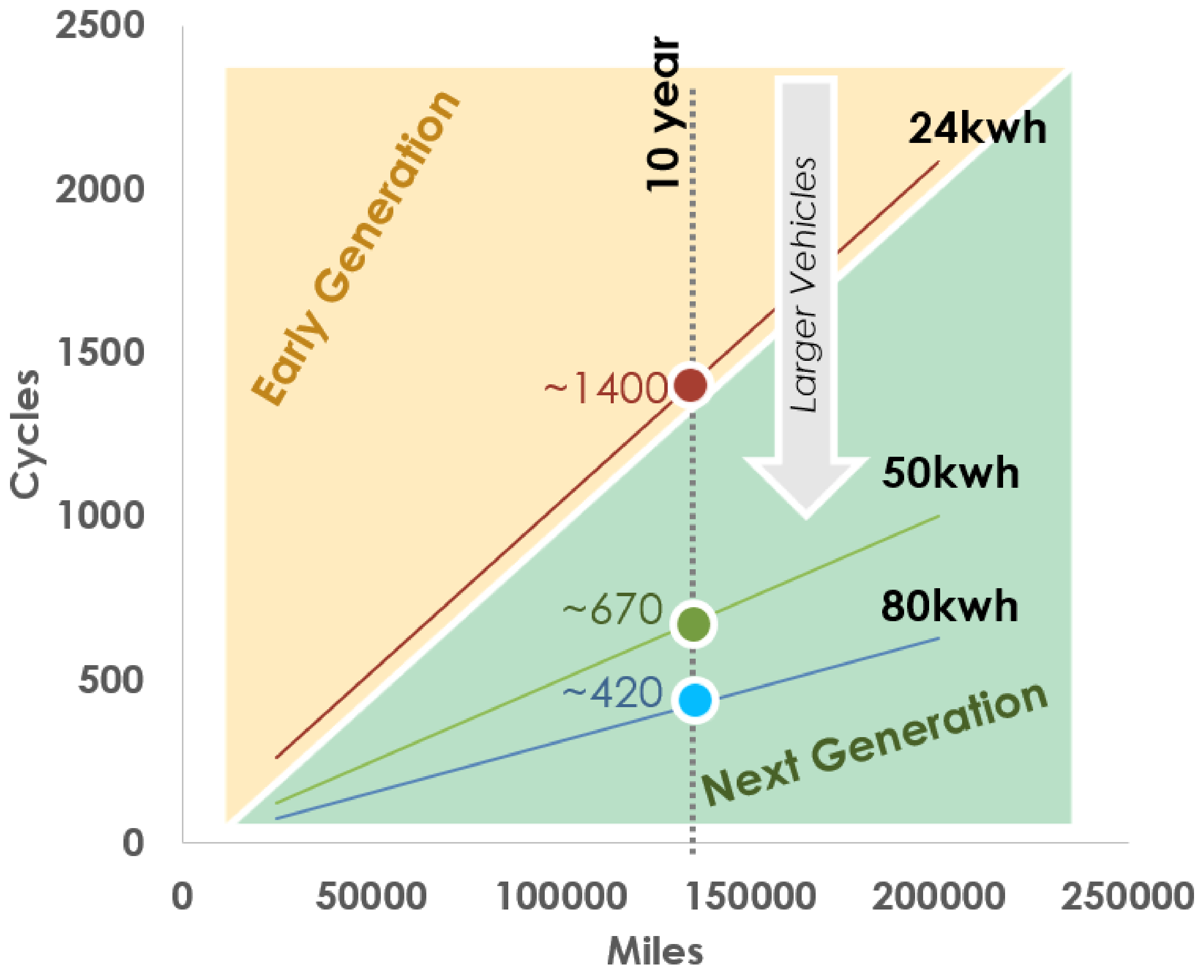
ORNL is managed by UT-Battelle, LLC for the US Department of Energy

Background : Secondary Use Energy Storage

The growth in demand for electric vehicles and size of electric vehicle battery systems.

- Potential increasing battery life following a primary use .
- Leveraging existing battery systems to their full life supply chain issue



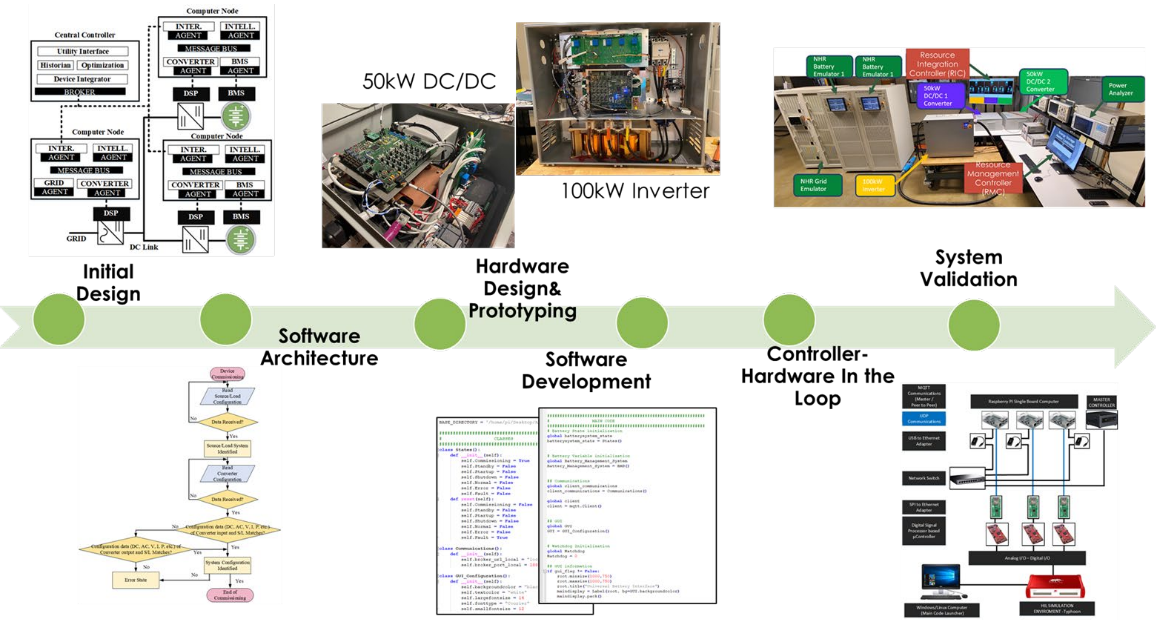
Potential battery cycling versus miles for different battery sizes

* 13,476 miles/year , 4mile/kWh

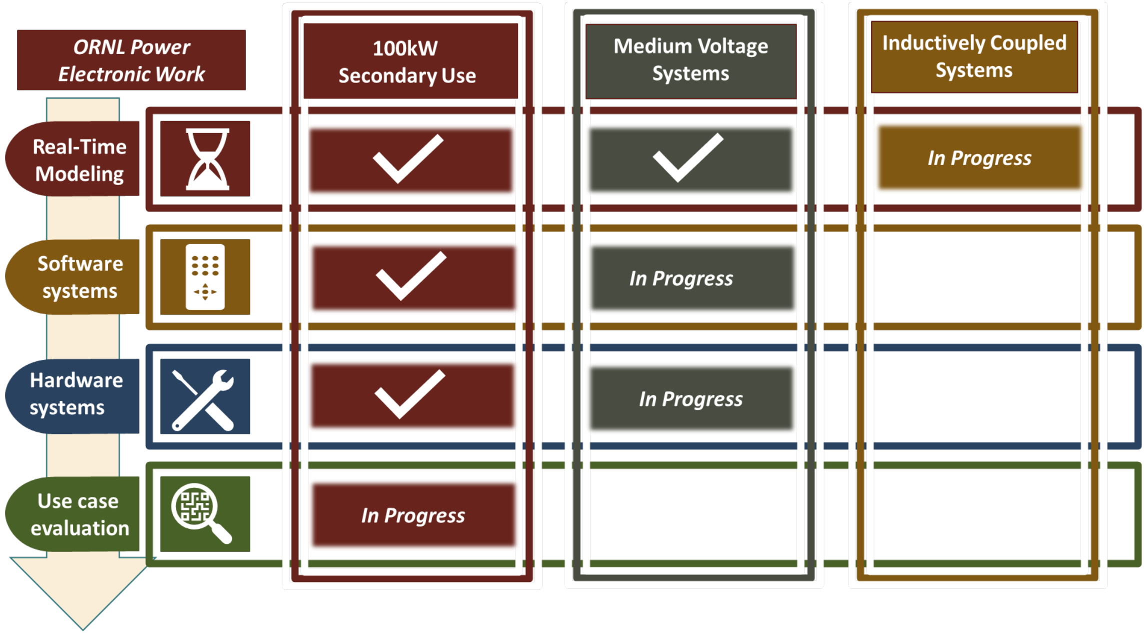
ORNL Project Portfolio Overview

Objective : Drive **industry acceptance** by solving the challenges of integrating multiple **secondary use energy storage systems** developing additional features, increased functionality and **demonstrating** the technology

Overall Approach



Project Portfolio



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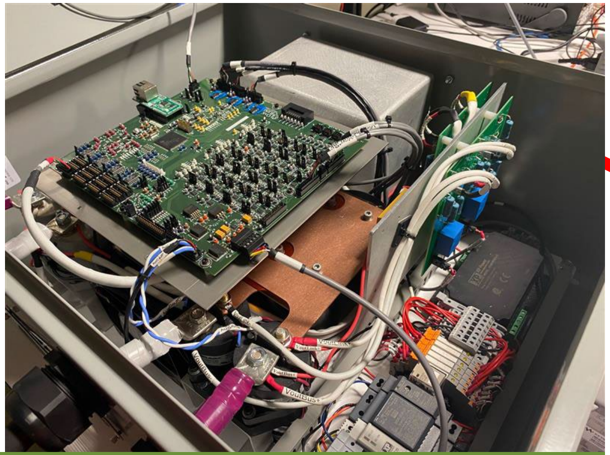
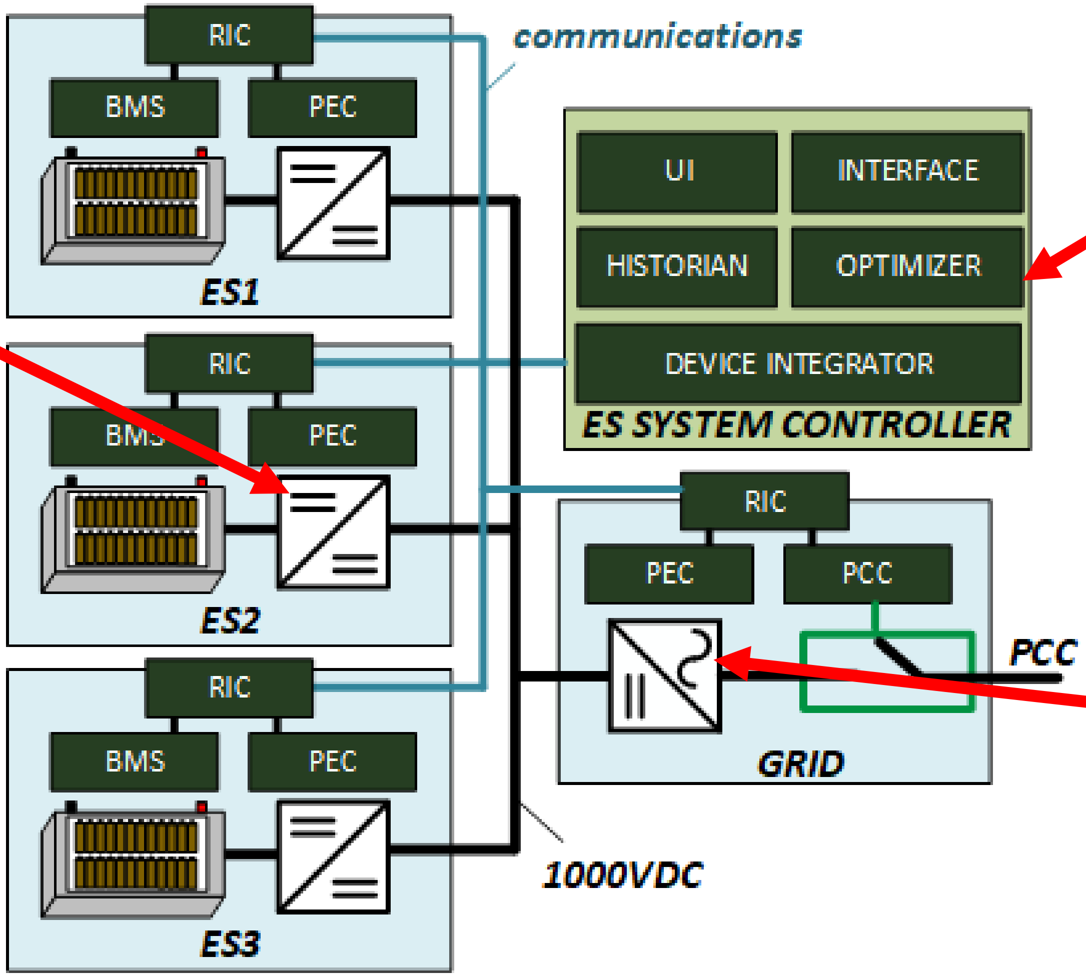
100kW Secondary Use System Prototype

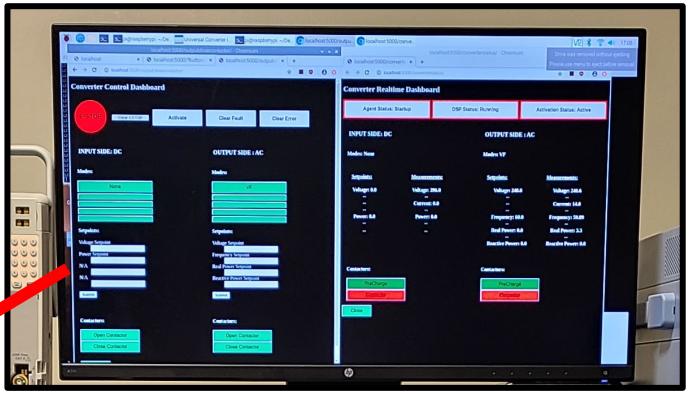
Objectives:

- Plug and Play energy storage system with 50kW blocks of secondary use batteries.
- Should support optimization and controls for grid integration.



ORNL Developed 50 kW DC-DC

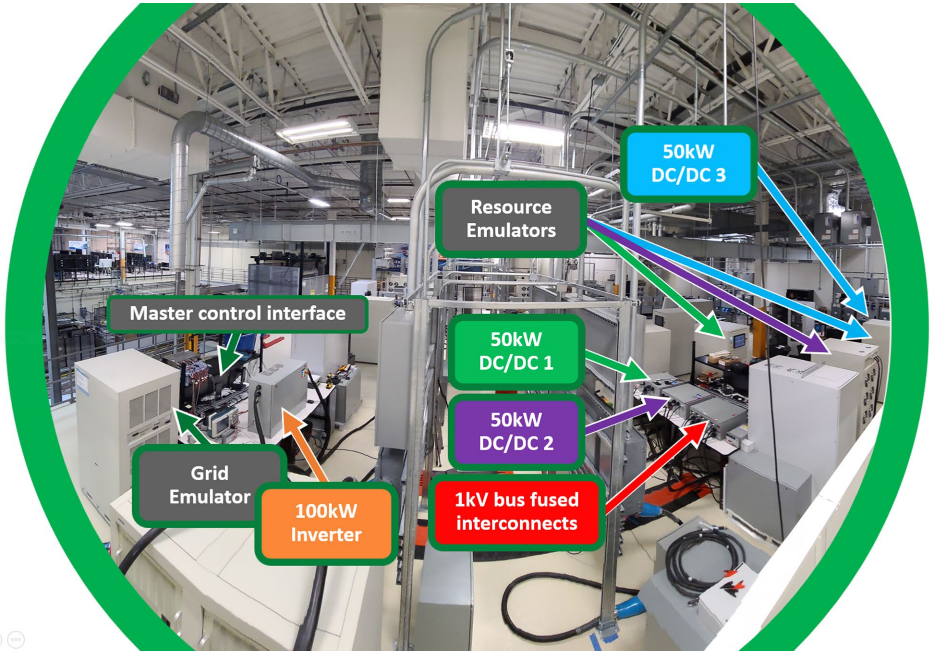


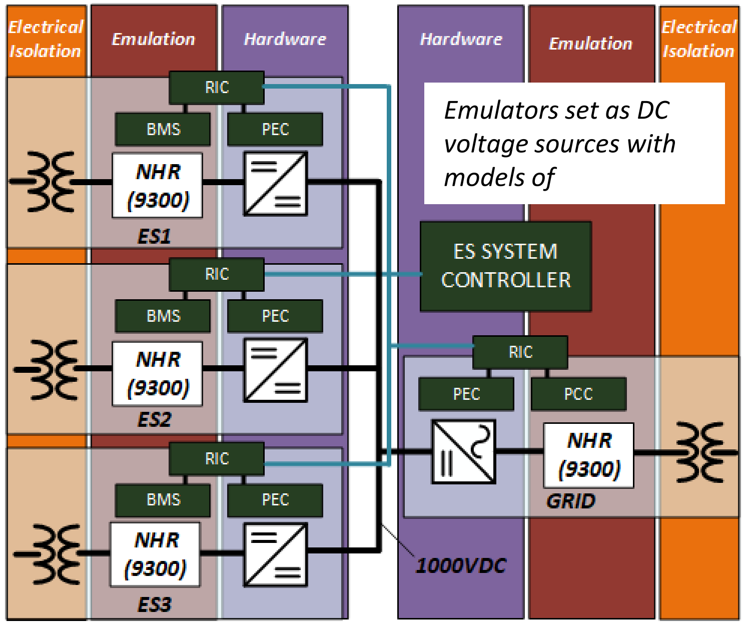


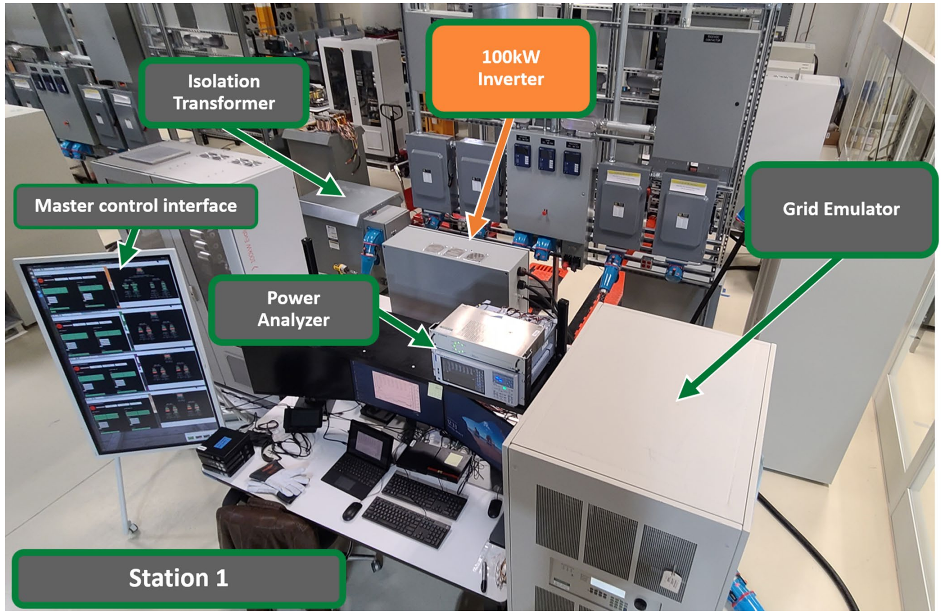
ORNL Developed Software Interface

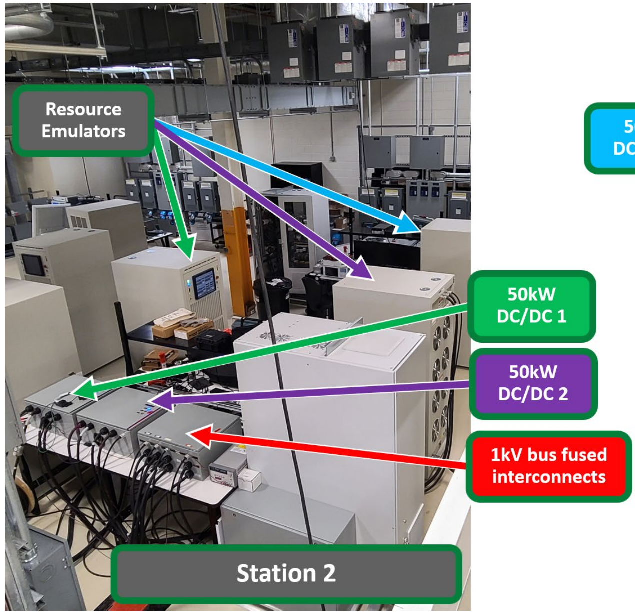
ORNL Developed 100 kW Inverter

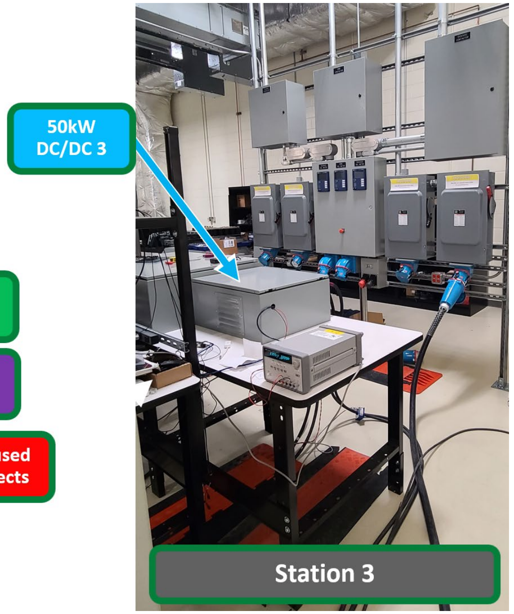
Implementation: Hardware Testbed in GRID-C @ ORNL: AC-DC Hybrid Infrastructure Lab



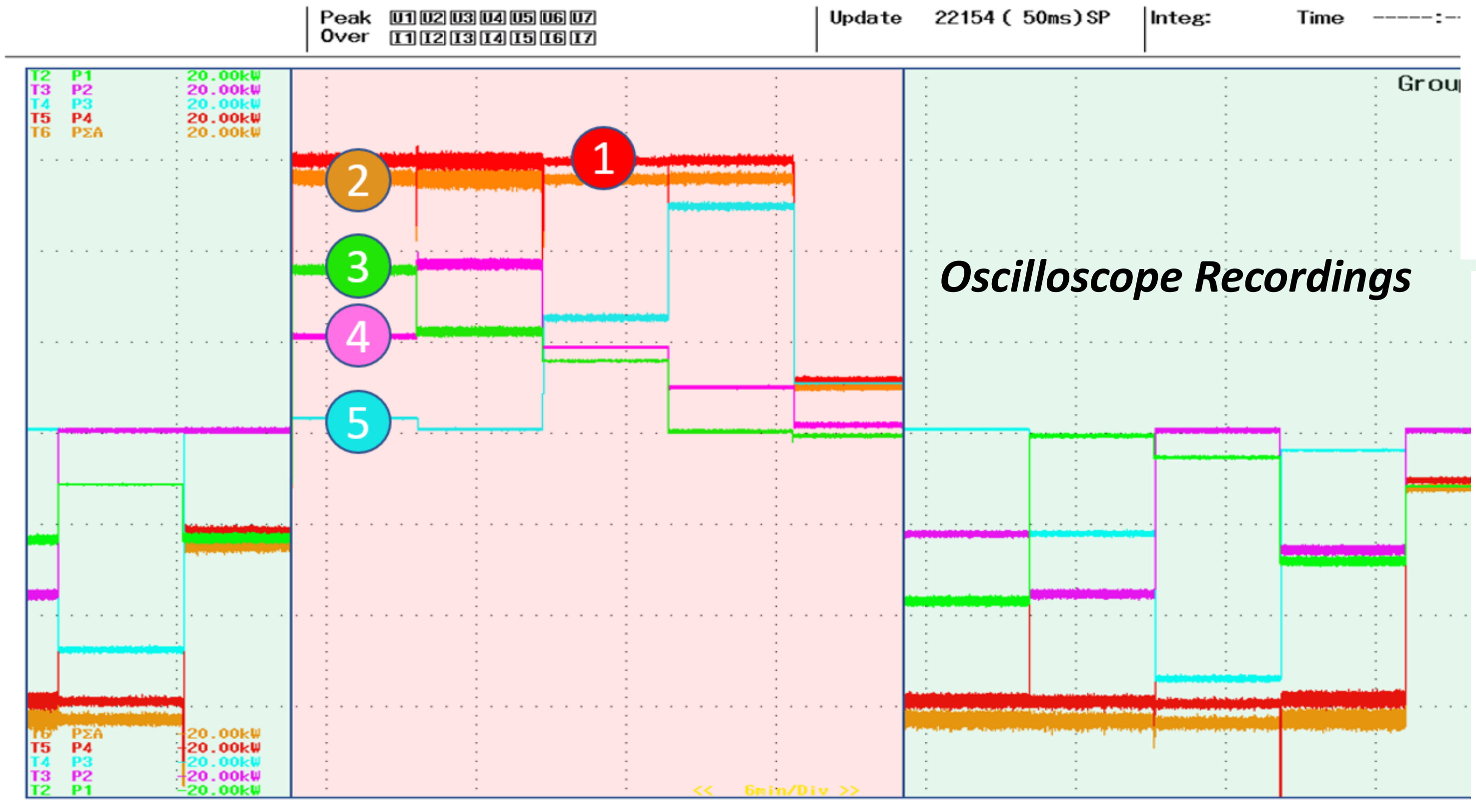




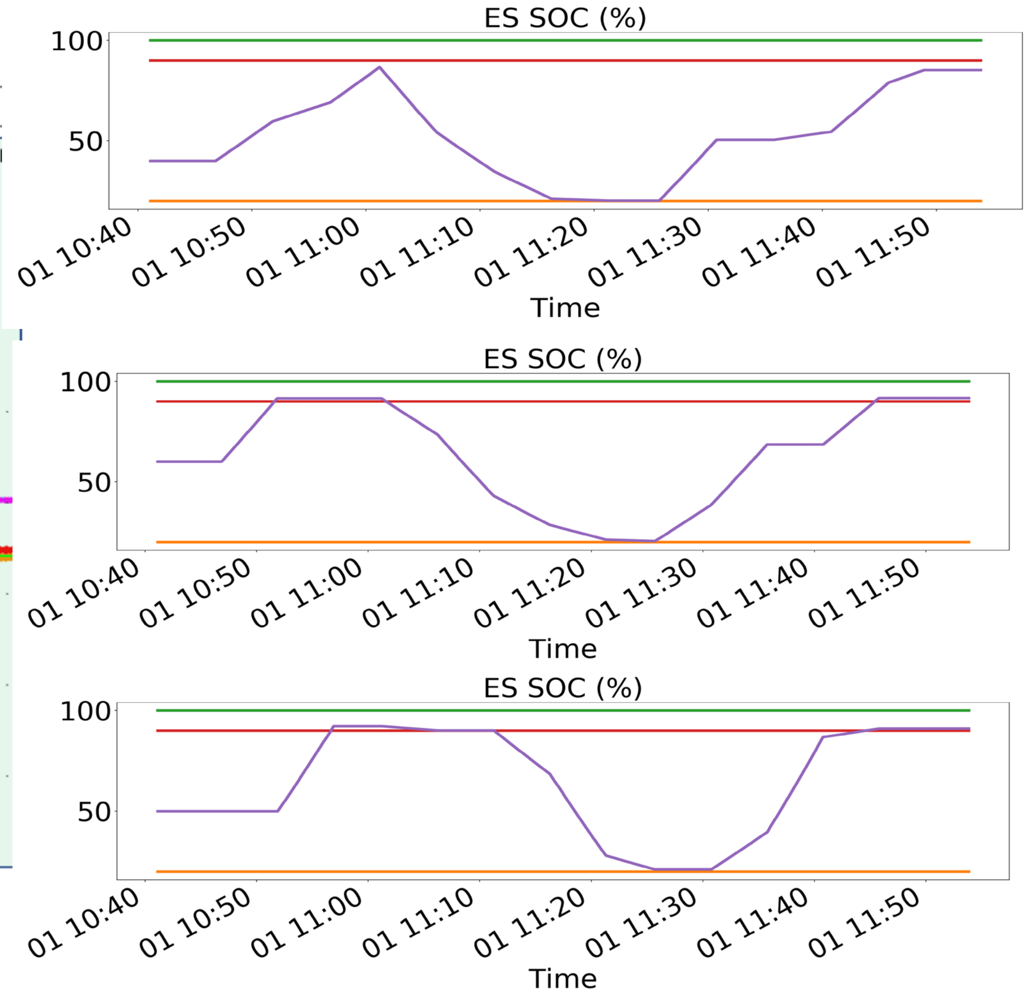




Experiment Results: Demonstration of Energy Full Charge/Discharge Test and Optimization of Modules



Measured power: 1) Inverter AC side power (red), 2) inverter DC side power (orange), 3) ES1 power (green), 4) ES2 power power (purple), and 5) ES3 power (blue)



Corresponding SOC values associated with collected data from the central controller: a) ES 1, b) ES 2, and c) ES 3; reported SOC (purple) SOC max operational limit (red), and SOC min operational limit (orange)

Medium Voltage Energy Storage Interface

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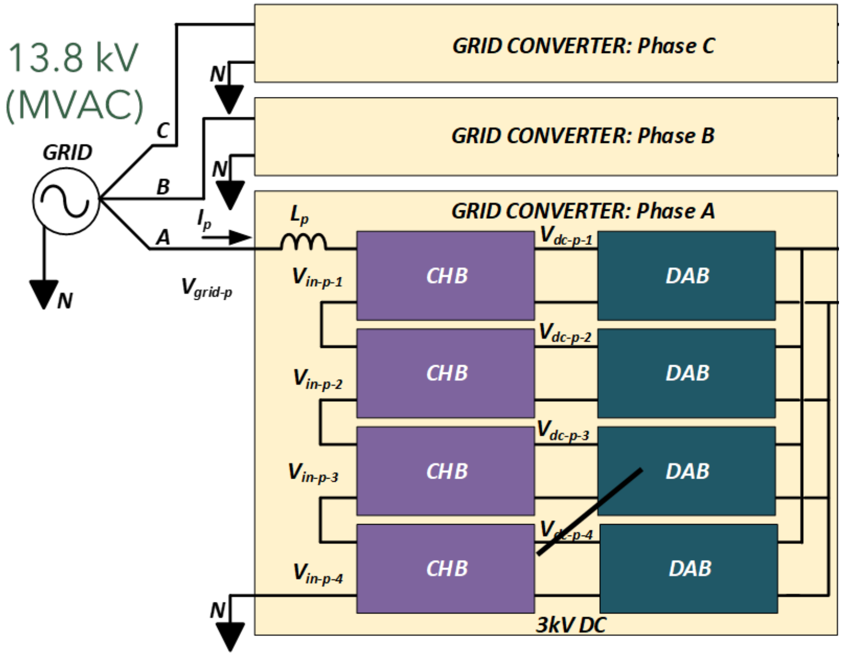
Objectives:

- Develop and validate novel **modular, scalable**, power electronics topology for directly interfacing energy storage to medium voltage grid (> 4.16 kV)
  - ✓ Provide ancillary services for distribution grid.
  - ✓ Improve the power density

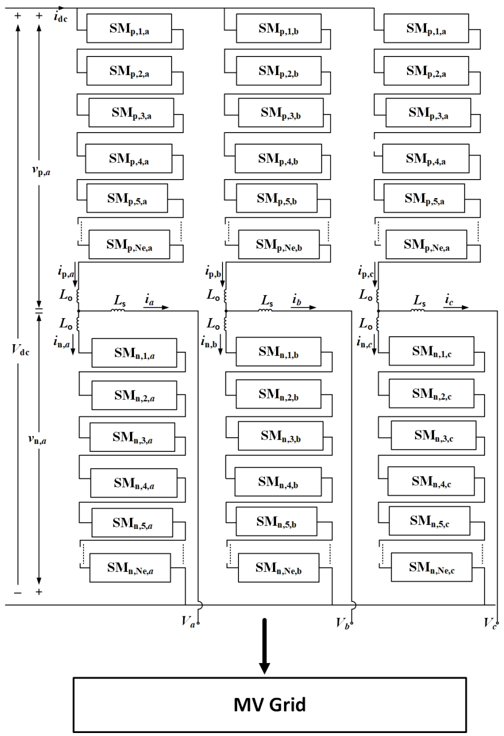
Background

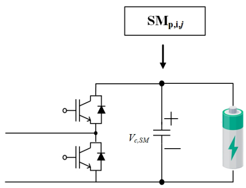
- Multi-level topologies with a single large DC-link [1]: require energy storage with large nominal voltages (>1kV)
- Topologies with distributed energy storage require complex control strategies to limit phase power imbalance [2]
- DC-DC converters needed for isolation and voltage scaling

CHB-DAB Topology



MMC Topology





[1] A. B. Chivukula and S. Maiti, "Analysis and control of modular multilevel converter-based E-STATCOM to integrate large wind farms with the grid," in IET Generation, Transmission & Distribution, vol. 13, no. 20, pp. 4604-4616, 22 10 2019.
[2] T. D. C. Busarello, A. Mortezaei, A. S. Bubshait, and M. Simões, "Three-phase battery storage system with transformerless cascaded multilevel inverter for distribution grid applications," IET Renew. Power Gener., vol. 11, no. 6, pp. 742–749, Mar. 2017

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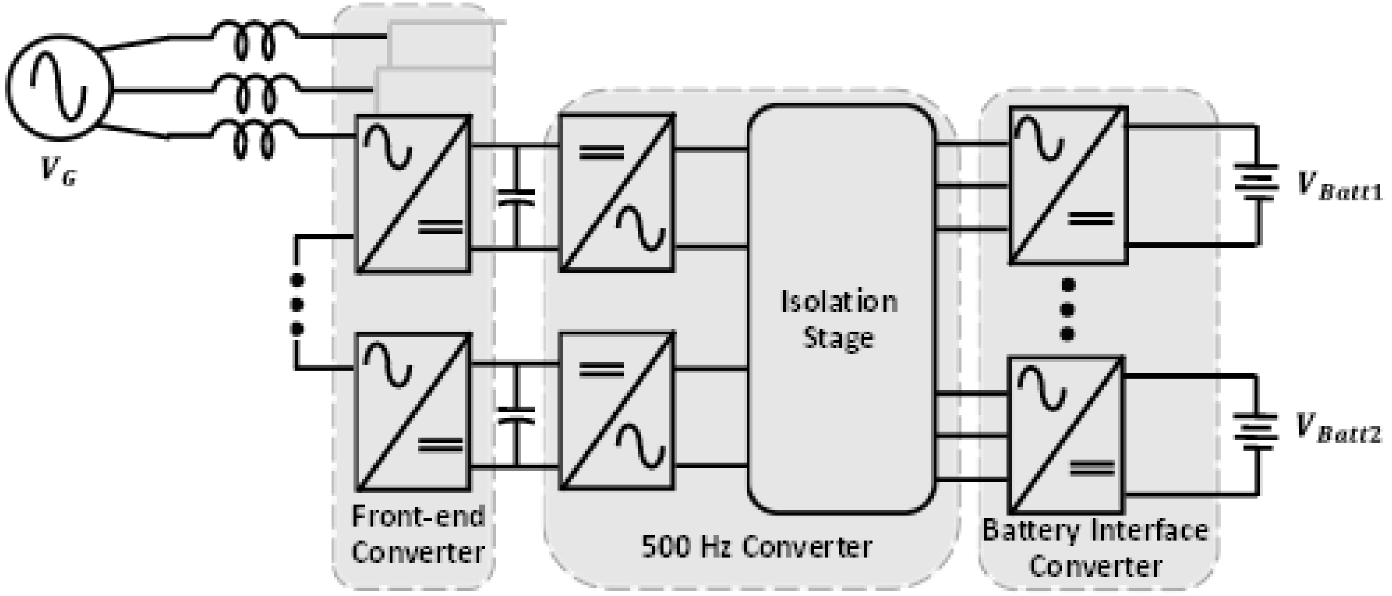
Medium Voltage Energy Storage Interface: Novel Topology

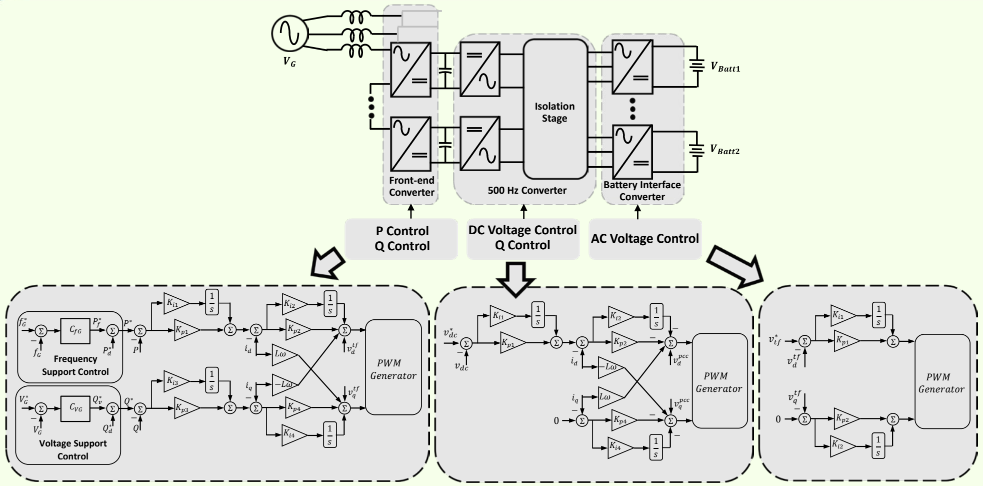
- ✓ A three-stage topology constructed 2-level AC/DC and H-bridge units.
- ✓ The use of medium frequency transformer for both isolation and voltage translation capability eliminates the need for a grid-side 60 Hz transformer and
  - improves the overall power density and efficiency of the system.
- ✓ Eliminates the need for DC-DC stages
- ✓ Allows use of 2-L converter and commercially available battery units.
- ✓ Modular architecture enables easy scalability to several MV levels and power levels, while enabling fault tolerant operation.

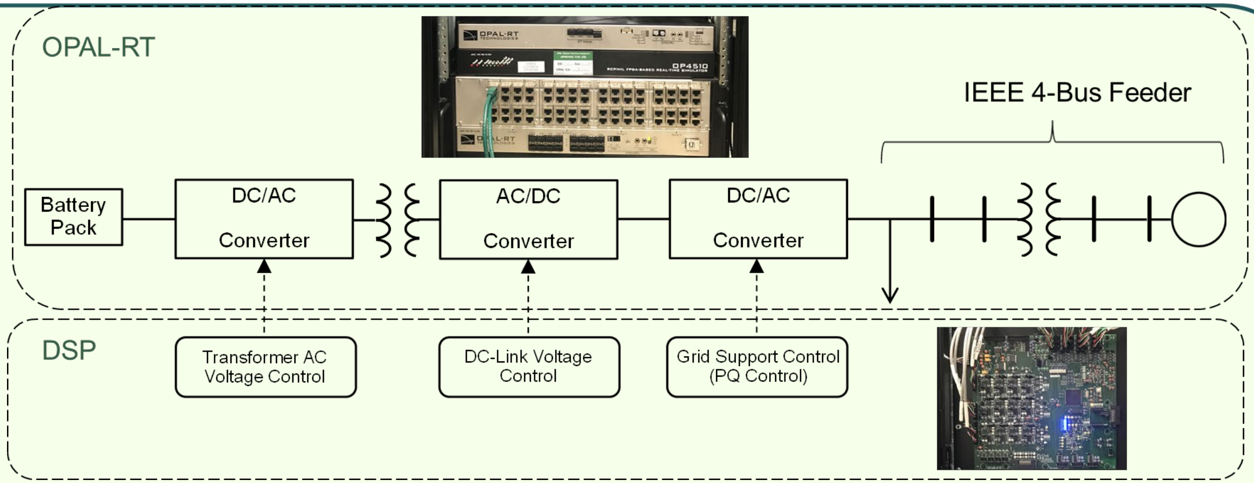


MVES Medium Voltage PE system developed @ ORNL

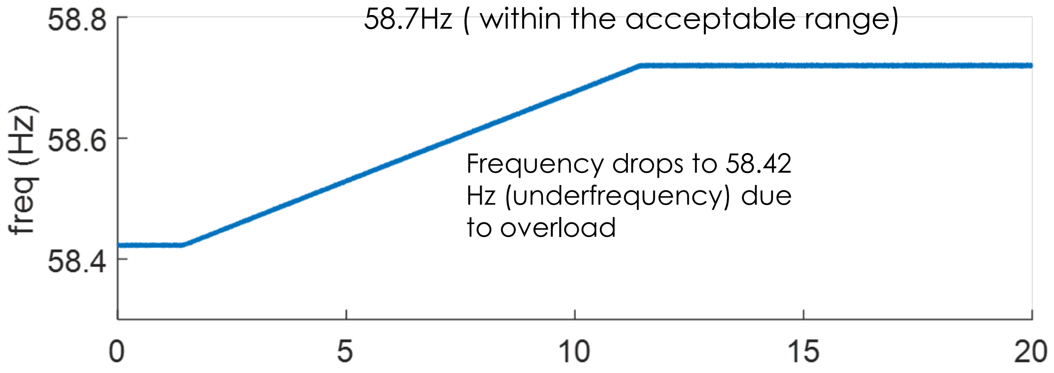
		Device (kV)	Conv. Params.	Power (kVA) 100 kVA FEC, MFC	100 kVA BIC	250 kVA FEC, MFC	250 kVA BIC	500 kVA FEC, MFC	500 kVA BIC	1000 kVA FEC, MFC	1000 kVA BIC
Grid Voltage (kV)	4.16	3.3	IT	5L-CHB	TLI	5L-CHB	3P-TLI	5L-CHB	5P-TLI	5L-CHB	10P-TLI
			Vdc	2 kV		2 kV		2 kV		2 kV	
			NT	2		2		2		2	
			NB	1		3		5		10	
		10	IT	TLI	TLI	TLI	3P-TLI	TLI	5P-TLI	TLI	10P-TLI
			Vdc	7 kV		7 kV		7 kV		7 kV	
			NT	1		1		1		1	
			NB	1		3		5		10	
	13.8	3.3	IT	13L-CHB	TLI	13L-CHB	3P-TLI	13L-CHB	5P-TLI	13L-CHB	10P-TLI
			Vdc	2.2 kV		2.2 kV		2.2 kV		2.2 kV	
			NT	6		6		6		6	
			NB	1		3		5		10	
		10	IT	5L-CHB	TLI	5L-CHB	3P-TLI	5L-CHB	5P-TLI	5L-CHB	10P-TLI
			Vdc	6.6 kV		6.6 kV		6.6 kV		6.6 kV	
			NT	2		2		2		2	
			NB	1		3		5		10	

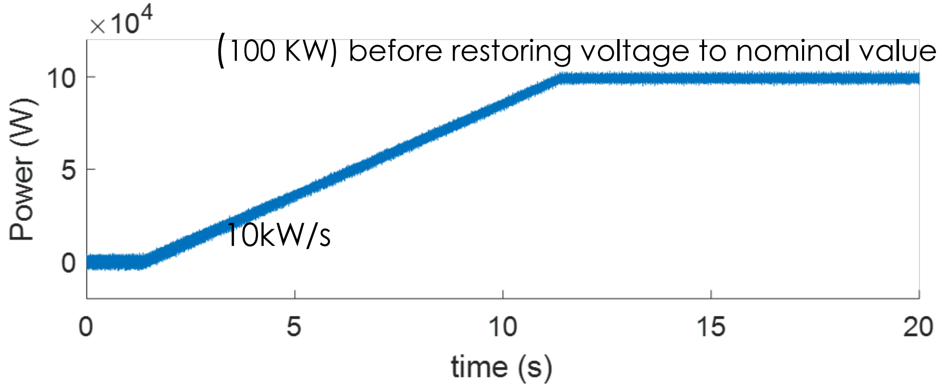
Medium Voltage Energy Storage Interface Real-Time Simulation

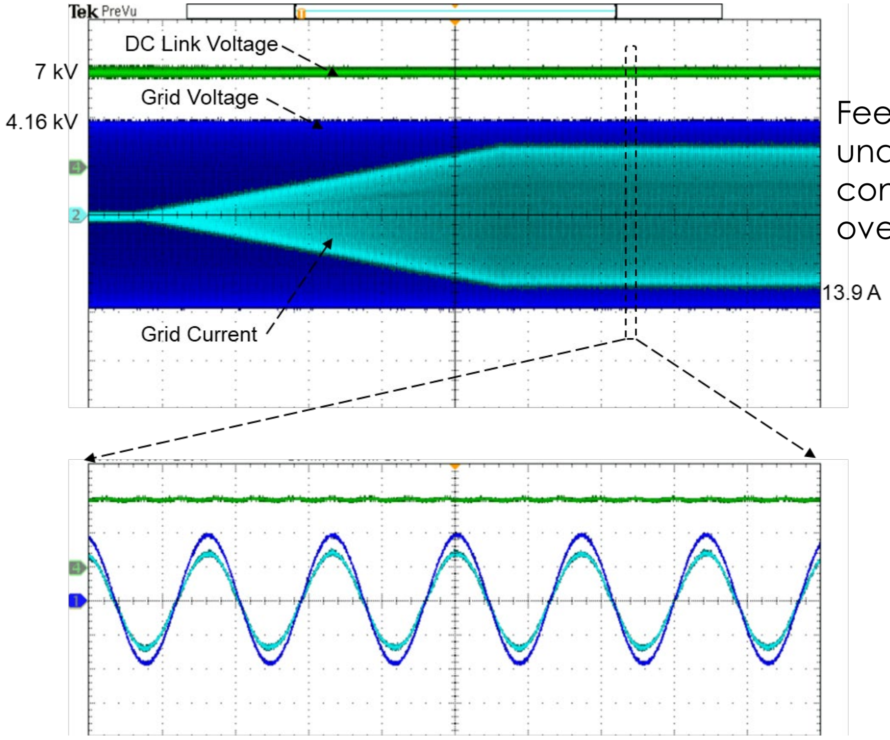




CHIL Simulation: MV-ES (2, 50 kWhr , 3ph Inverter, 3 2-L 10 kv, b2b)connected to IEEE 4-nodes feeder (modified to behave as a 4.16kV weak grid)







Feeder in underfrequency condition due to overload

Medium Voltage Energy Storage Interface: Component Design

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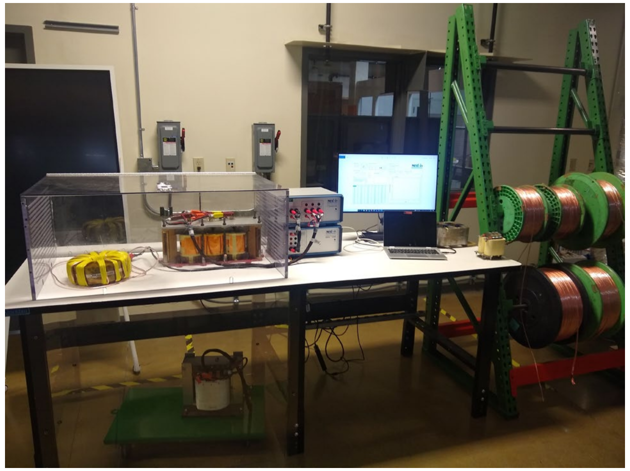
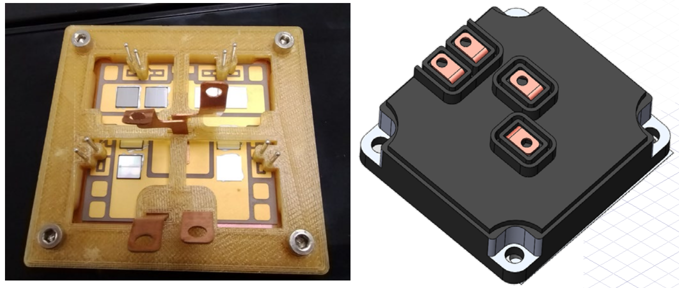
Device Packaging facility: clean room in GRID-C @ ORNL

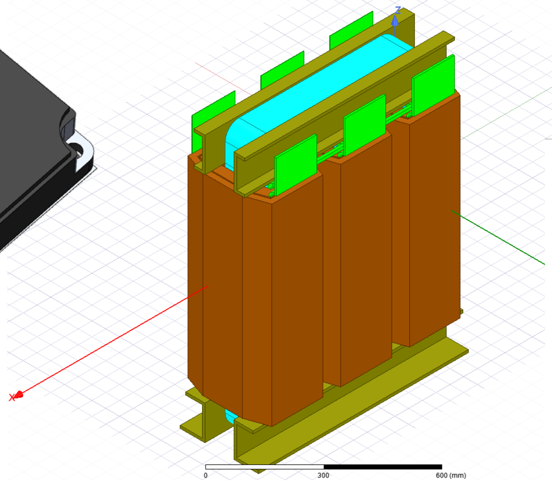
Magnetics Build and Test Setup in GRID-C @ ORNL



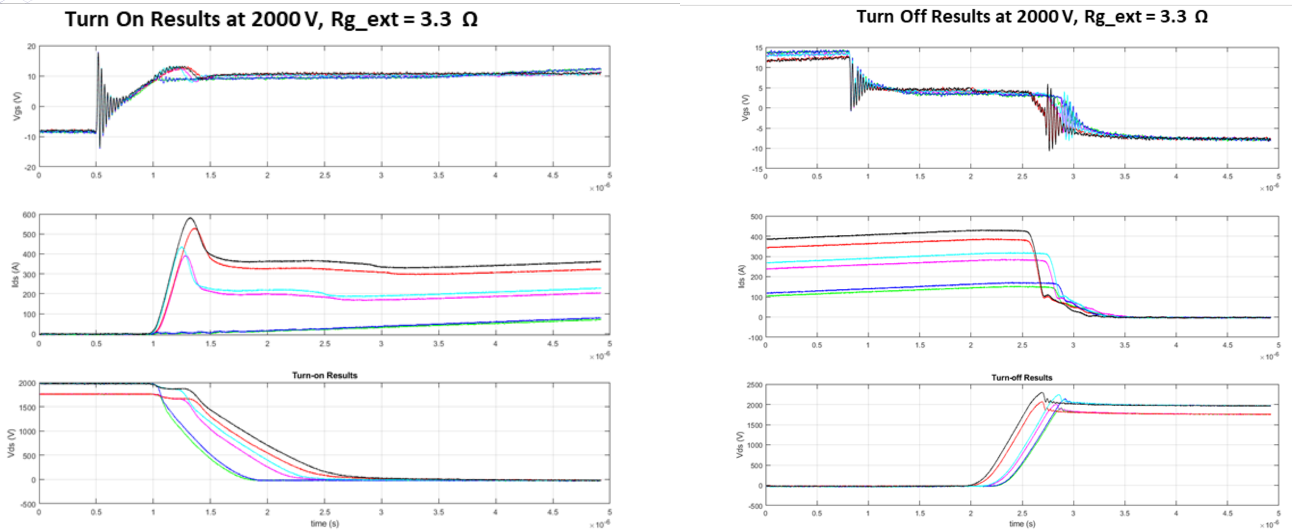
Medium voltage Lab Setup in GRID-C @ ORNL



ORNL Medium Voltage Power Module : 3.3 - 10 kV



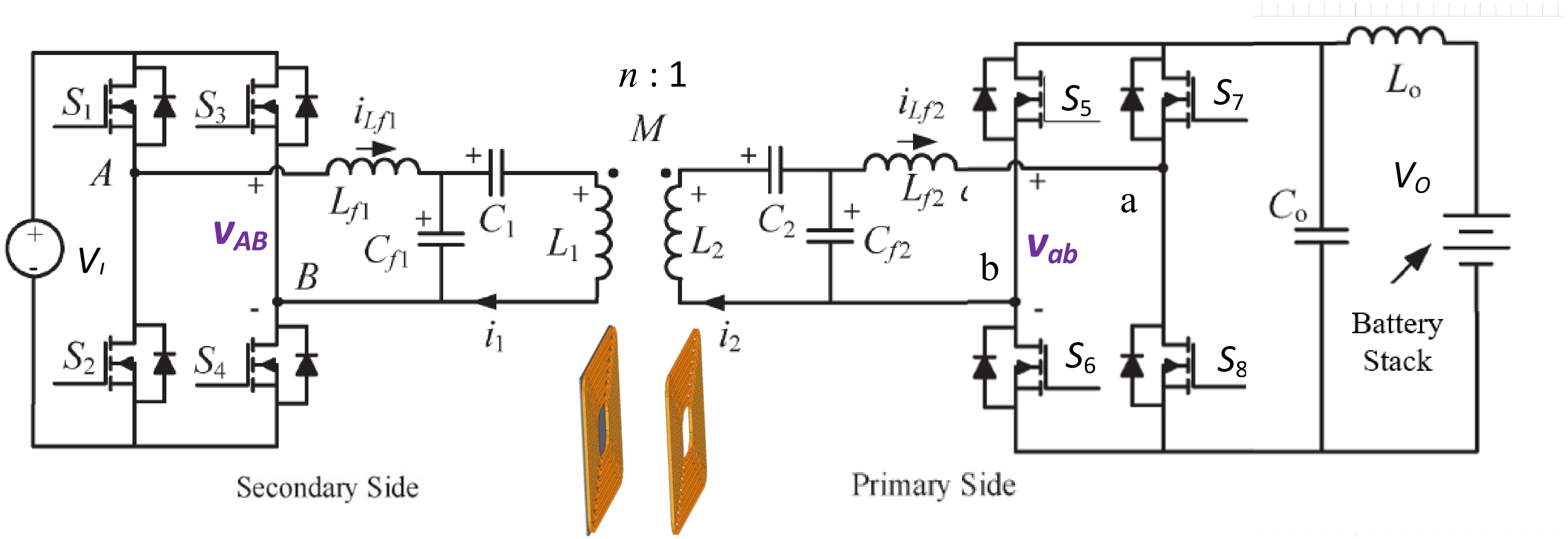
A 1MVA 500Hz transformer designed with primary and secondary voltages of 4.16kV and 208V, 30 x 12 x 38 in^3, 109mH, peak magnetic field density 1.47T, amorphous core



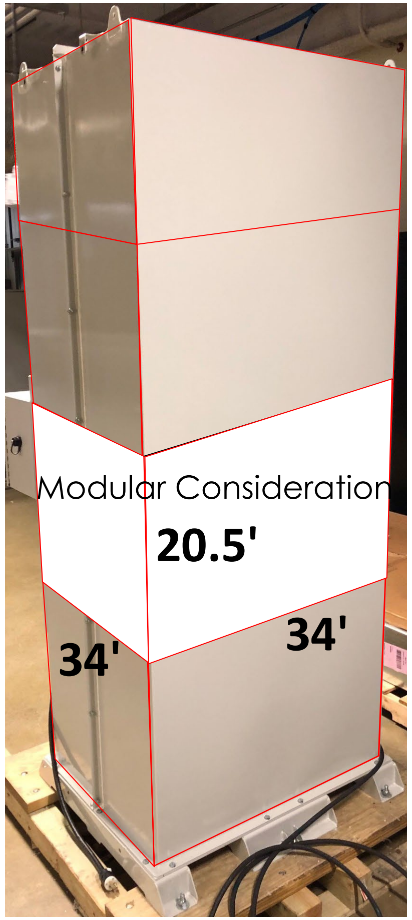
Double Pulse data from 3.3 kV Si module evaluation

Integrated Inductively coupled dc-dc battery interface for Safety for Secondary Use

- Objective: Develop a safe hardware plug-and-play integration approach for battery systems



- ORNL has extensive past work in inductive power transfer technologies
- Design is highly modular and would provide easy maintenance of ES technologies.
- Provides electrical isolation between grid and battery interconnections.



50kWhr Secondary Use

Expected Outcome: Plug-and-play modules that can be pulled while active.

FY22 Accomplishments

- Completed the integration of multiple **(three) DC/DC** and AC/DC power electronics systems prototypes for the 100 kW secondary use systems and ran the optimization use case for at scale ES system with emulators.
- Completed the development CHIL for MVESS and evaluated the system for two use cases : frequency and voltage regulation
- Completed the initial study on the Integrated Inductively coupled dc-dc battery interface for Safety for Secondary Use.

FY22 Publications: 1 Journal, 4 Conference papers

M. Starke, B. Dean, S. Campbell, M. Chinthavali, "An Intelligent Power Electronic System for Secondary Use Batteries, EESAT 2022. (accepted)

M. Chinthavali et al., "A Medium Voltage Three-Stage Power Converter Topology for Distribution Grid Scale Energy Storage Systems," ECCE 2022. (accepted)

M. Starke et al., "Agent-Based Distributed Energy Resources for Supporting Intelligence at the Grid Edge," in IEEE Journal of Emerging and Selected Topics in Industrial Electronics, vol. 3, no. 1, pp. 69-78, Jan. 2022.

M. Starke, R.K.Moorthy, S. Campbell, M. Chinthavali, "Start-up Optimization Considering Integrated Power Electronic Systems," IEEE Power and Energy General Meeting, July 2022.

M. Starke et al., "A Remote Development Process and Platform for Power Electronic Systems," 2021 IEEE Energy Conversion Congress and Exposition (ECCE), 2021, pp. 3182-3189.

Future Work and Acknowledgments

Future Work:

- Complete the advance functions of the 100 kW 480 V ESS system prototype
- Evaluate deployment and Long-term testing Opportunities and utilize the system to support field issues in collaboration with partners
- Continue the design and development of the novel medium voltage ESS prototype
- Design the components for the inductively coupled system and evaluate prototype feasibility
- Continue to work on publications

Acknowledgments

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