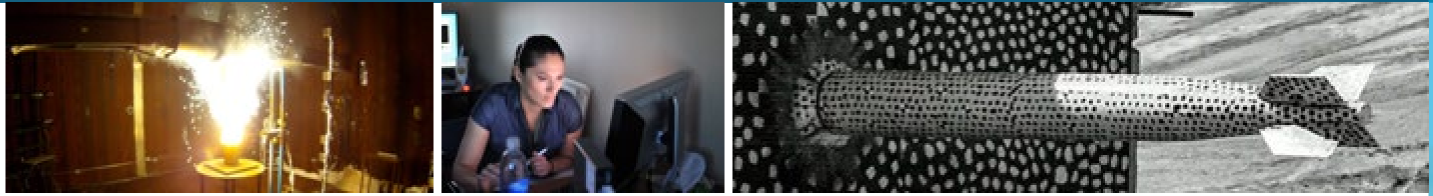
Development of Modular Hardware Architectures for Medium Voltage Energy Storage Systems



PRESENTED BY

Jake Mueller

Project Team: Luciano Garcia Rodriguez, Andy Dow, Michael Rios
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Presentation ID: 802

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Power Capacity Need for a Net-Zero 2050 Scenario

How much capacity* do we need from storage?

- Up to 460GW from long duration storage by 2050[1]
- About 160GW from short duration storage by 2050[2]

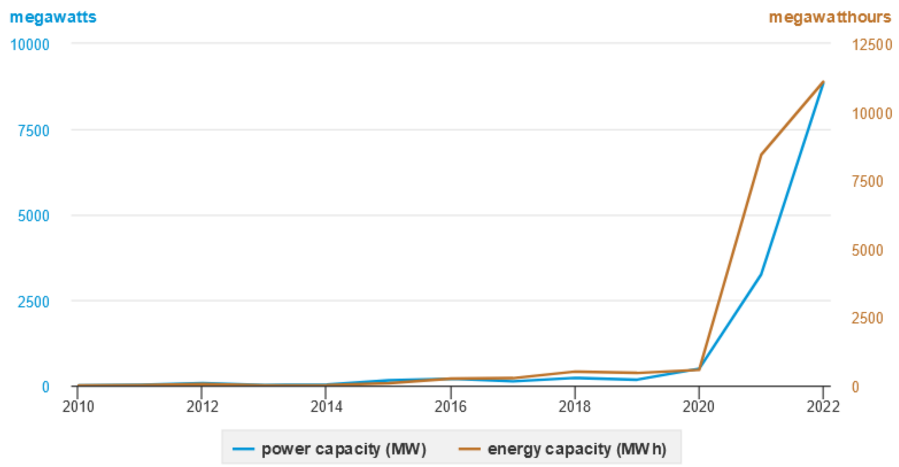
*For power electronics, MW is more meaningful than MWh

620GW in 26 years is…

… 24GW/year

… 65MW/day

…2.7MW/hour



U.S. battery storage capacity in 2010 through 2022

Data source: U.S. Energy Information Administration (EIA), *Annual Electric Generator Report* and *Preliminary Monthly Electric Generator Inventory*, February 2022

Note: MW is megawatts; MWh is megawatthours. Data are end-of-year operational nameplate capacities at installations with at least 1 MW nameplate power capacity.

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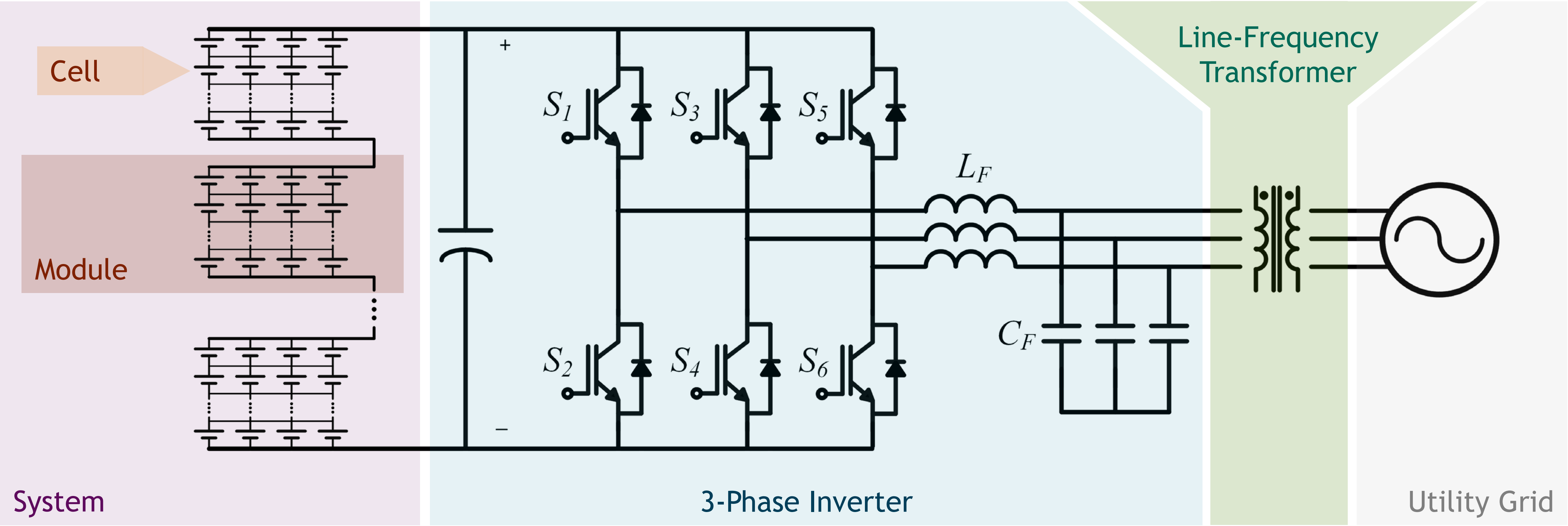
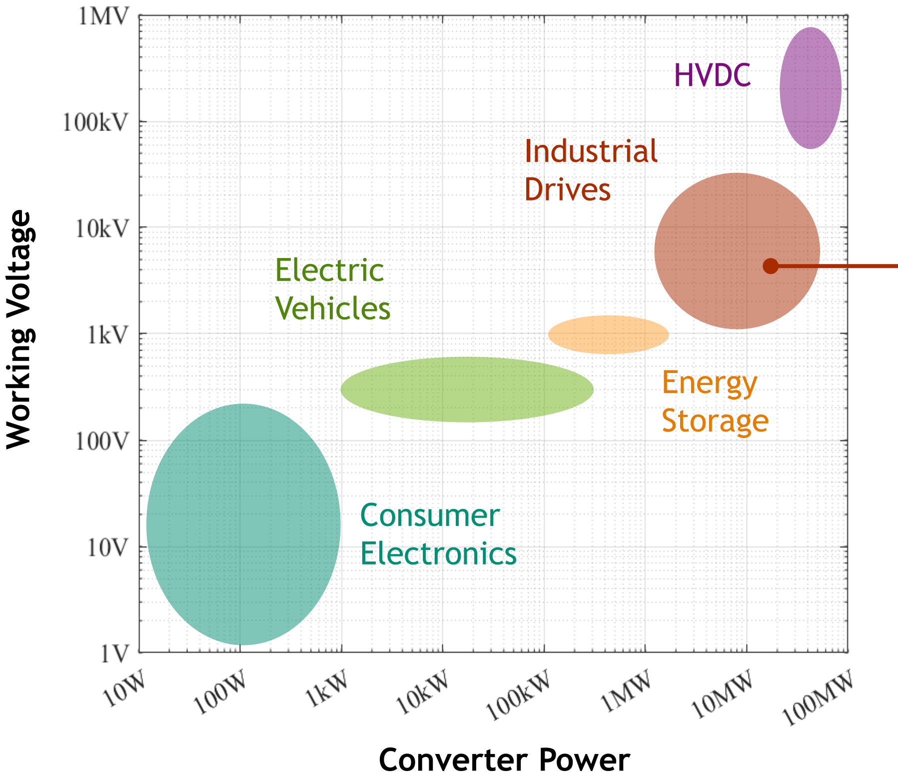
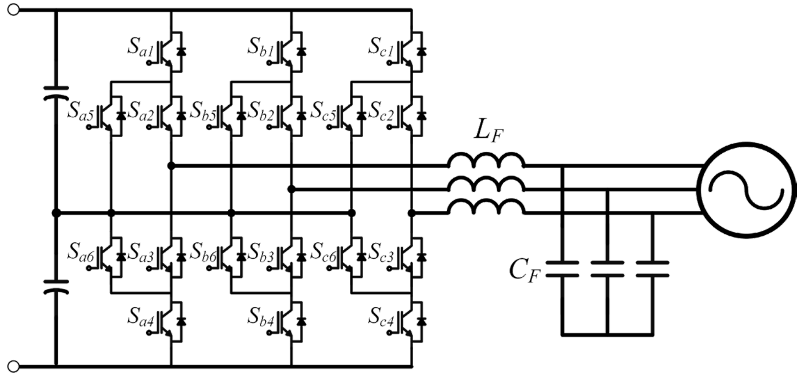
1. Pathways to Commercial Liftoff: Long Duration Energy Storage, U.S. Department of Energy
2. 2023 Annual Energy Outlook, U.S. Energy Information Administration

Conventional Power Conversion System



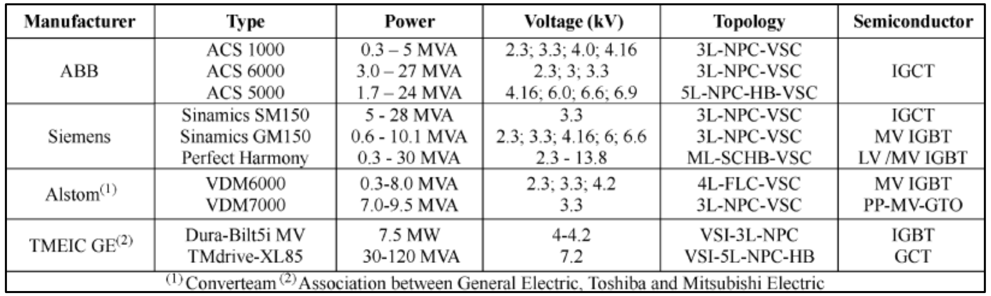
Power and Voltage Scaling in Power Electronic Systems





Multi-level Inverter (3-Level NPC Topology)

Overview of Industrial MV Drives

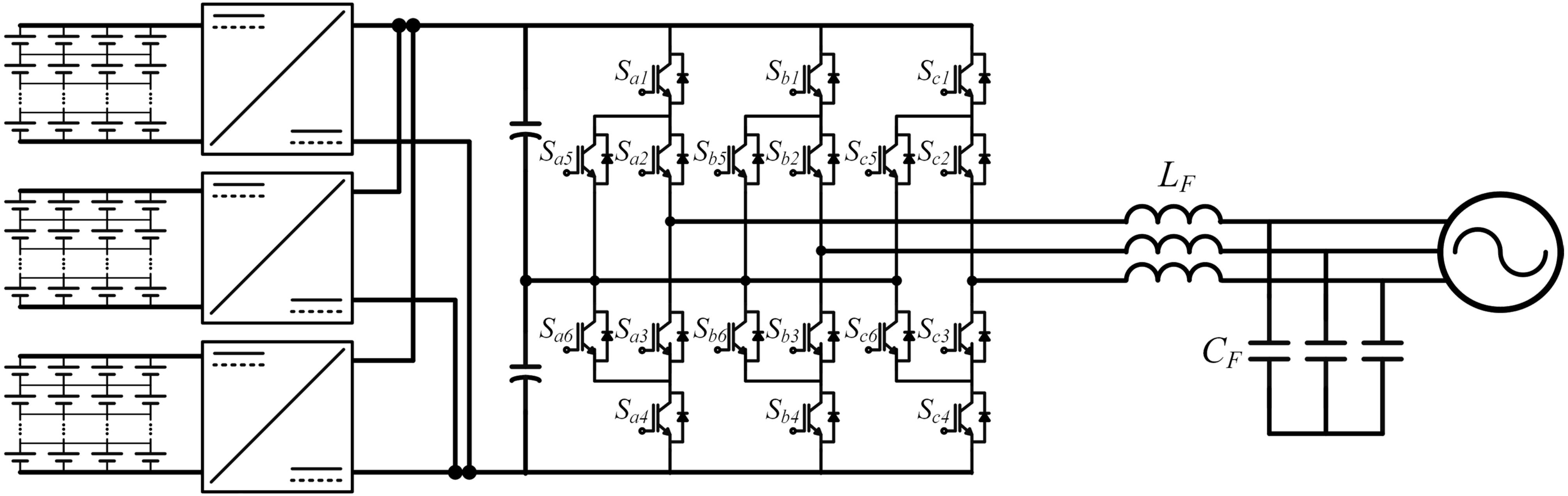


Manufacturer	Type	Power	Voltage (kV)	Topology	Semiconductor
ABB	ACS 1000 ACS 6000 ACS 5000	0.3 – 5 MVA 3.0 – 27 MVA 1.7 – 24 MVA	2.3; 3.3; 4.0; 4.16 2.3; 3; 3.3 4.16; 6.0; 6.6; 6.9	3L-NPC-VSC 3L-NPC-VSC 5L-NPC-HB-VSC	IGCT
Siemens	Sinamics SM150 Sinamics GM150 Perfect Harmony	5 - 28 MVA 0.6 - 10.1 MVA 0.3 - 30 MVA	3.3 2.3; 3.3; 4.16; 6; 6.6 2.3 - 13.8	3L-NPC-VSC 3L-NPC-VSC ML-SCHB-VSC	IGCT MV IGBT LV /MV IGBT
Alstom(1)	VDM6000 VDM7000	0.3-8.0 MVA 7.0-9.5 MVA	2.3; 3.3; 4.2 3.3	4L-FLC-VSC 3L-NPC-VSC	MV IGBT PP-MV-GTO
TMEIC GE(2)	Dura-Bilt5i MV TMdrive-XL85	7.5 MW 30-120 MVA	4-4.2 7.2	VSI-3L-NPC VSI-5L-NPC-HB	IGBT GCT

(1) Converteam (2) Association between General Electric, Toshiba and Mitsubishi Electric

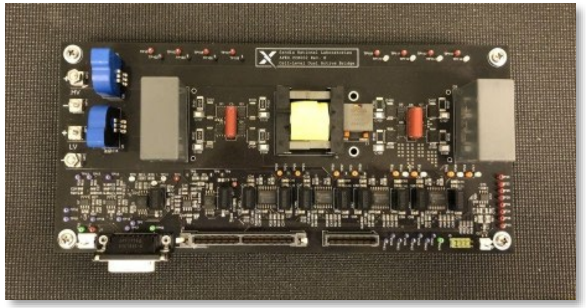
H. Abu-Rub, J. Holtz, J. Rodriguez and G. Baoming, "Medium-Voltage Multilevel Converters—State of the Art, Challenges, and Requirements in Industrial Applications," in *IEEE Transactions on Industrial Electronics*, vol. 57, no. 8, pp. 2581-2596, Aug. 2010.

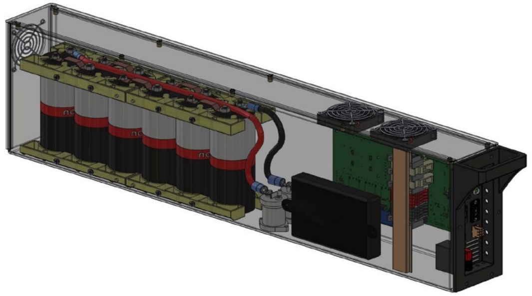
Parallel Multi-Stage Power Conversion System

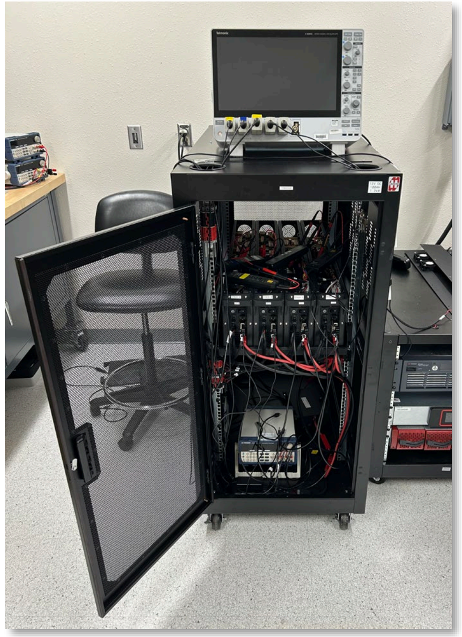


Previous Work – Parallel Systems

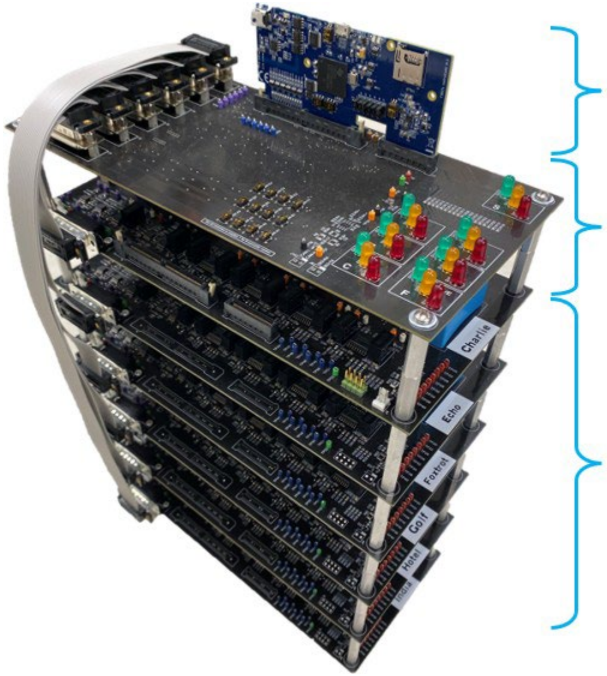
- Parallel system of isolated DC-DC converters tested in FY22
- Demonstrated 6x parallel converters, each with voltage gain of 6
- Strategic distribution of load among converters leads to efficiency improvements at the system level
- Integrated converters with gain of 2 into hybrid storage system with Li-ion and lead acid batteries







Parallel System Prototype

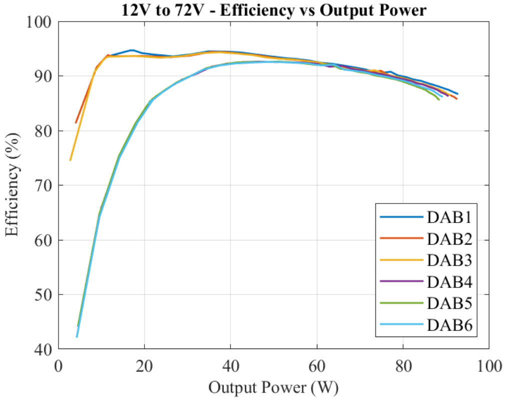


Control system implemented on TI C2000 series digital signal processor (DSP)

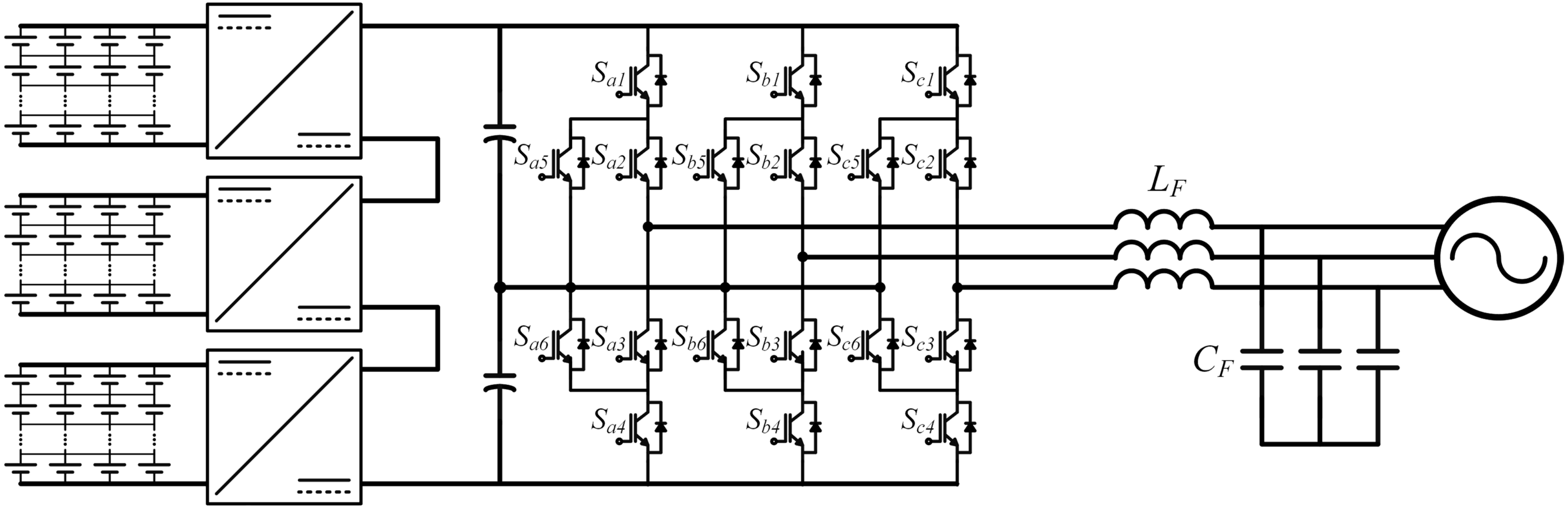
Central control board for I/O routing and analog sensor signal processing

6 DAB converters connected in Input-Parallel-Output-Parallel configuration

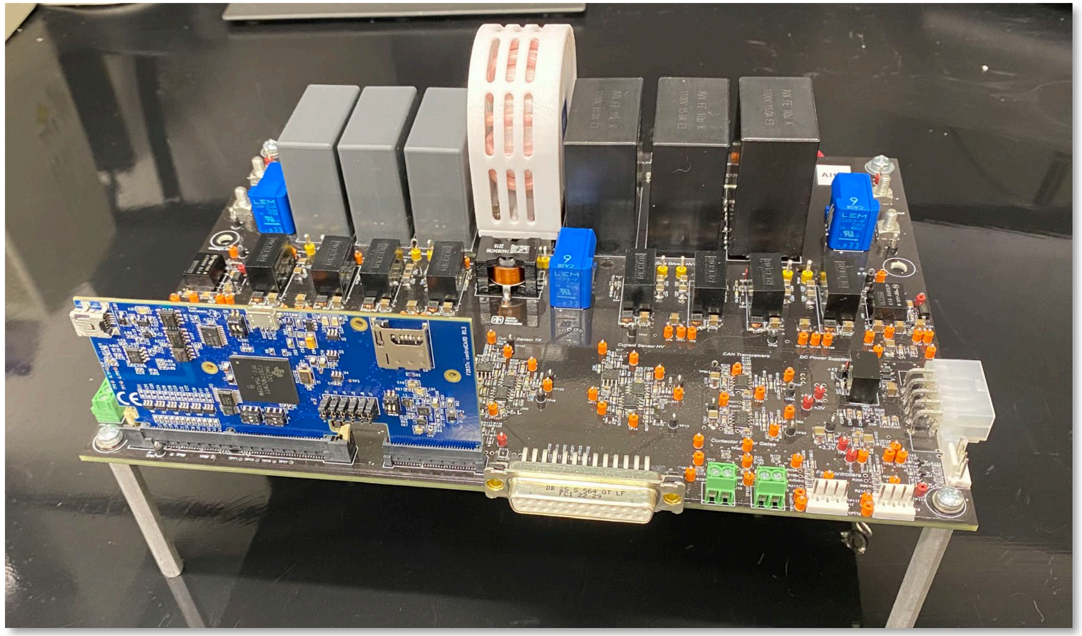
System Specifications	
Low-Side Voltage	12V nom
High-Side Voltage	72V nom
Switching Freq	100kHz
Rated Power (Module)	±85W
Transformer Turns Ratio	1:6
System Voltage Gain	6



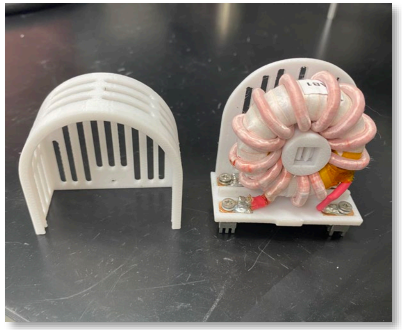
Series Multi-Stage Power Conversion System



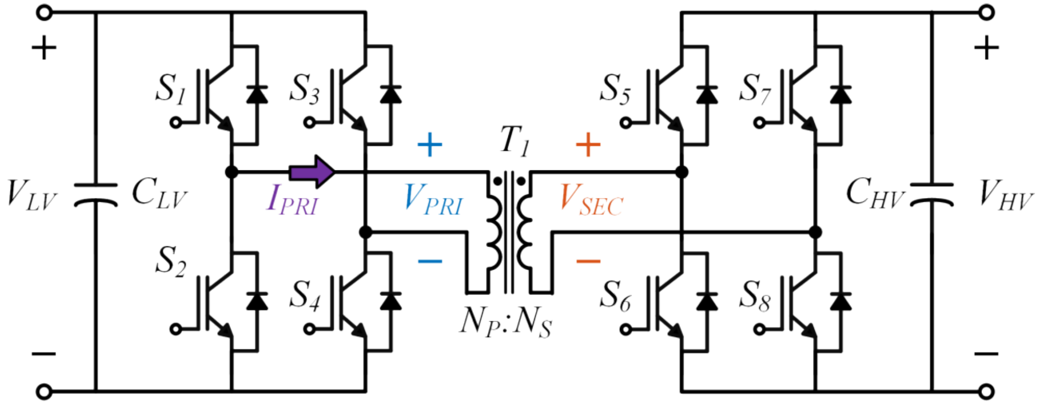
Isolated DC-DC Converter Prototype



Converter Specifications (Base Config)	
Nominal Low-Side Voltage	24V
Nominal High-Side Voltage	144V
Switching Frequency	100kHz
Rated Power	±350W
Transformer Turns Ratio	1:6
Leakage Inductance (Ref Secondary)	66μH



Custom Transformer Fixture

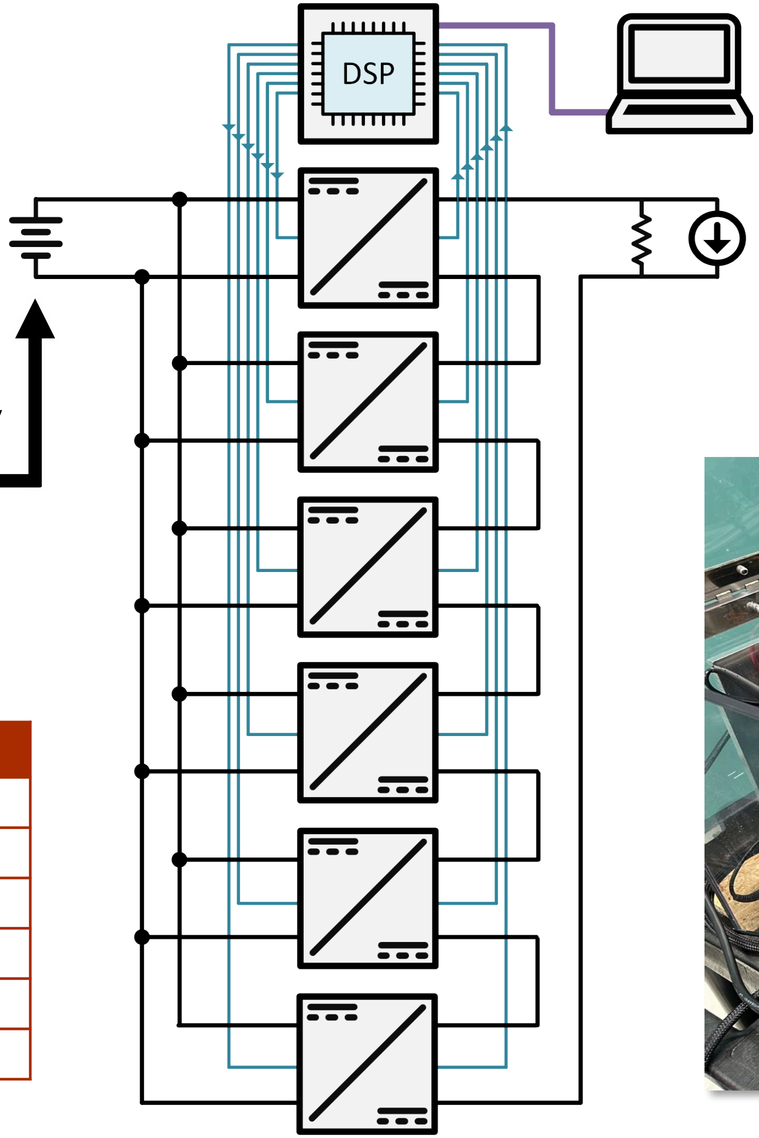


- Dual active bridge circuit topology
- Controlled via on-board DSP or external control board
- Local voltage, current, temperature sensing
- On-board contactor, indicator, and fan control
- Digital comms with higher level controllers (I2C, CAN, SCI)
- Ferrite core transformer with custom fixturing
  - Toroid for in-place replacement with experimental magnetics
- Voltage range intentionally overdesigned
  - 1200V SiC MOSFETs at high-voltage bridge
  - High-side creepage and clearance suitable for >1kV

System Configuration

Single Input Case

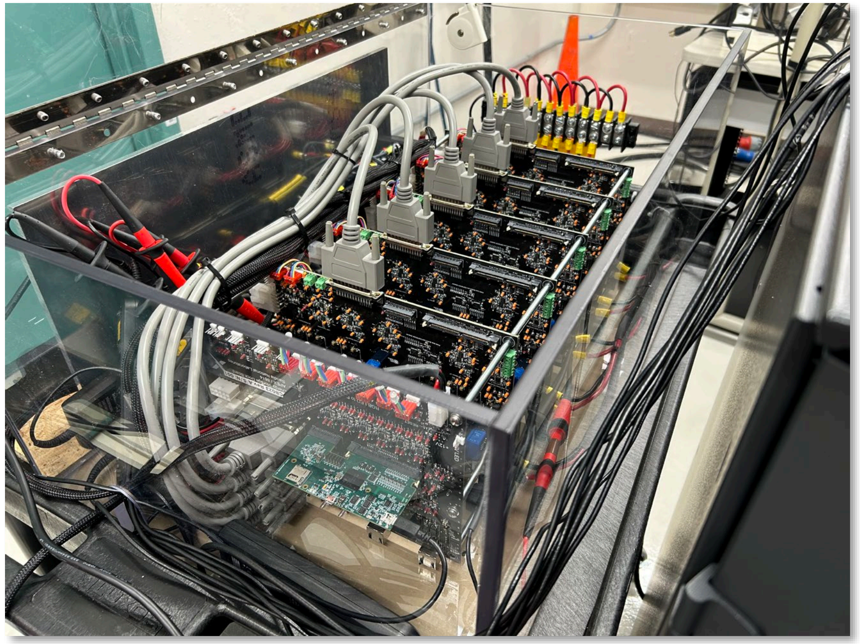
DC Power Supply
500V/40A/10kW



System Specifications	
Nominal Low-Side Voltage	24V
Nominal High-Side Voltage	864V
Number of Modules	6*
Rated Power (Module)	±350W
Rated Power (System)	±2.1kW
System Voltage Gain	**36**

*5 of 6 modules used in results on following slides

- Initial experiment is single-input case
- Fixed DC source at nominal input voltage
- Multi-converter system controlled by central DSP board
- Serial communication link with local PC for operator commands, datalogging, etc.

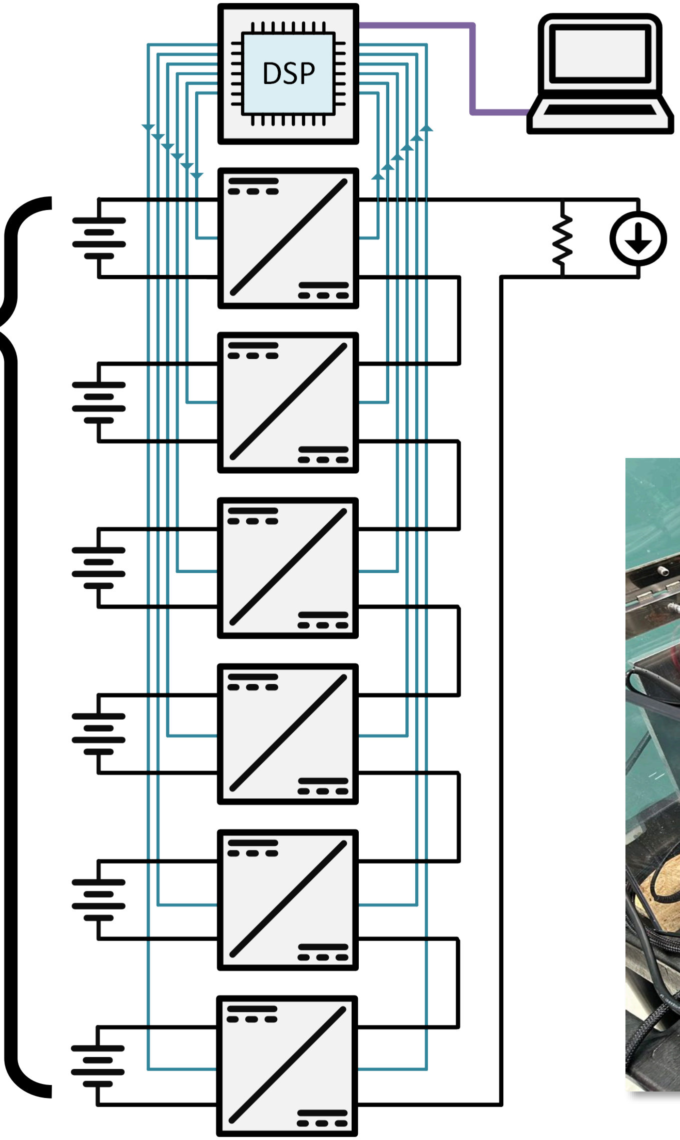


System Configuration

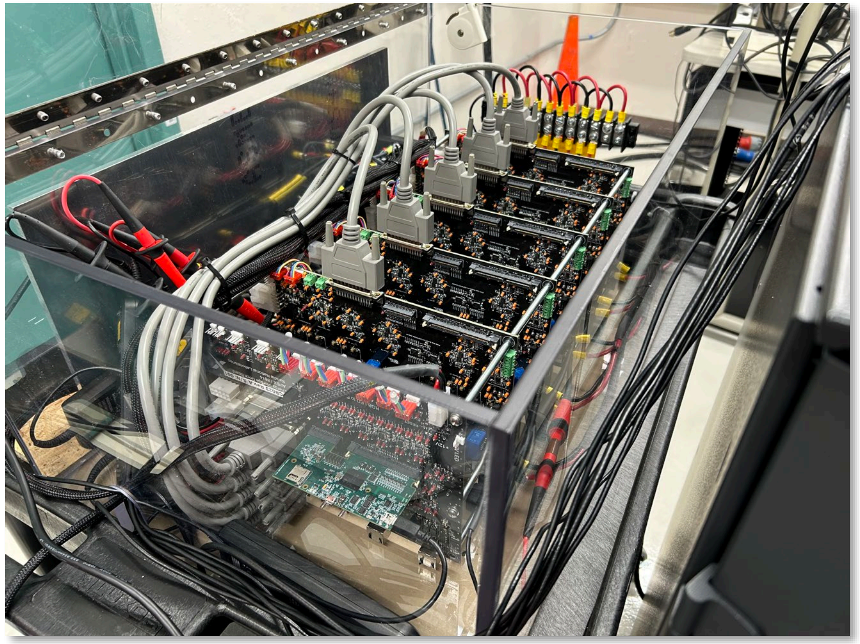
Independent Input Case

OPAL-RT runs real-time models of storage devices

6x DC Power Supplies 50V/20A/1kW



- System specifications are designed around APEX lab's battery emulation capabilities
- Up to 12 bidirectional DC power supplies, controlled in real-time via OPAL-RT OP5700
- Programmable storage device parameters for emulation of different chemistries, power/energy capacities, states of health, etc.



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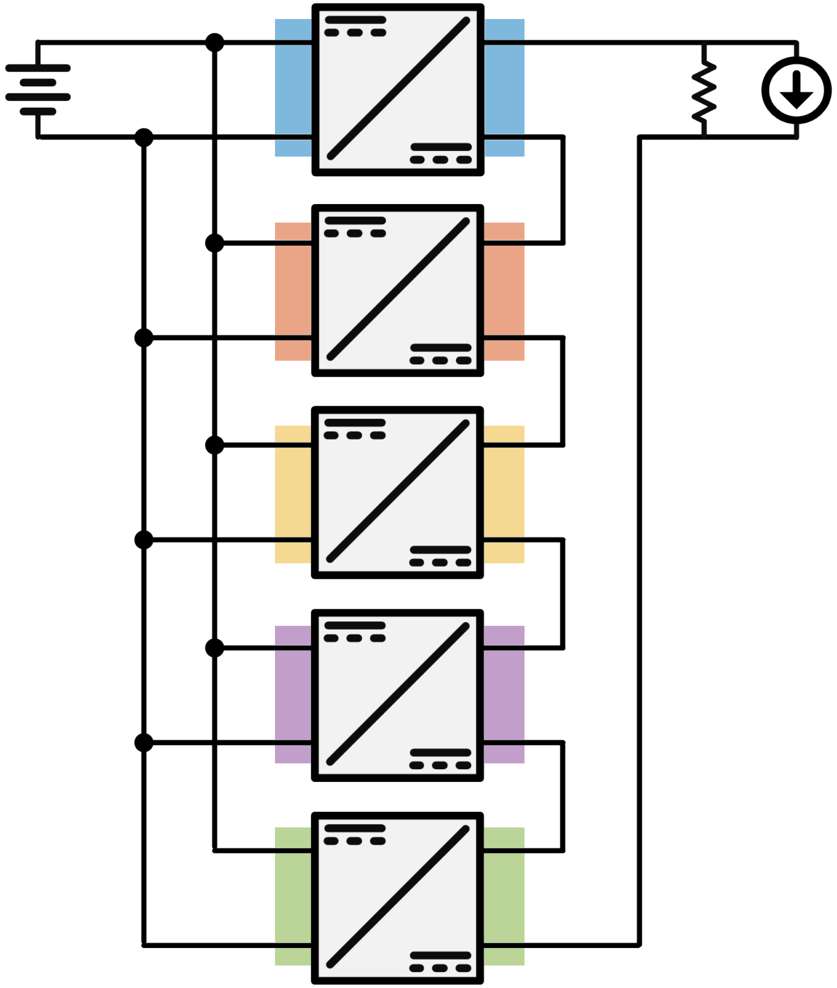
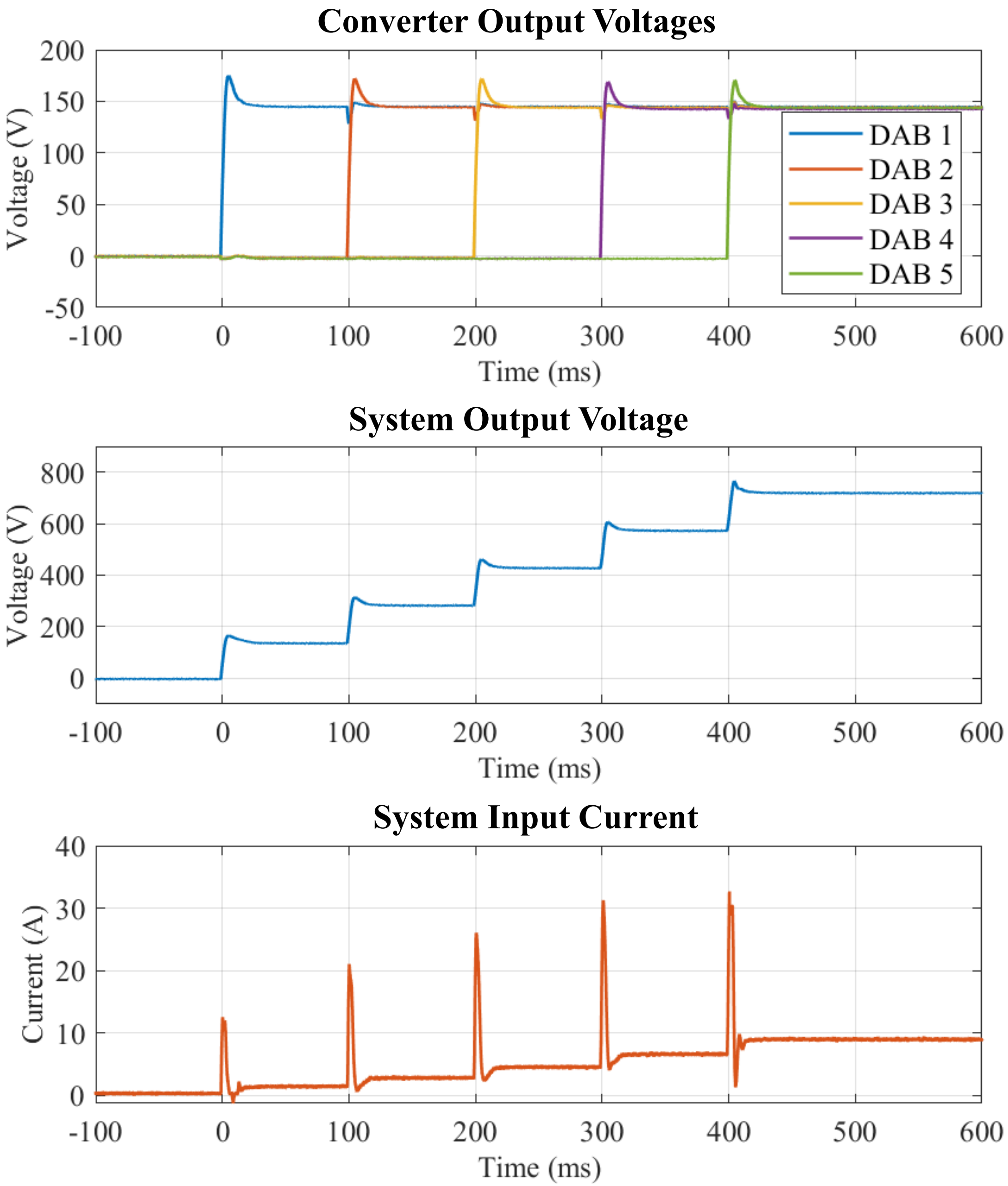
Hardware Results – Startup Transient

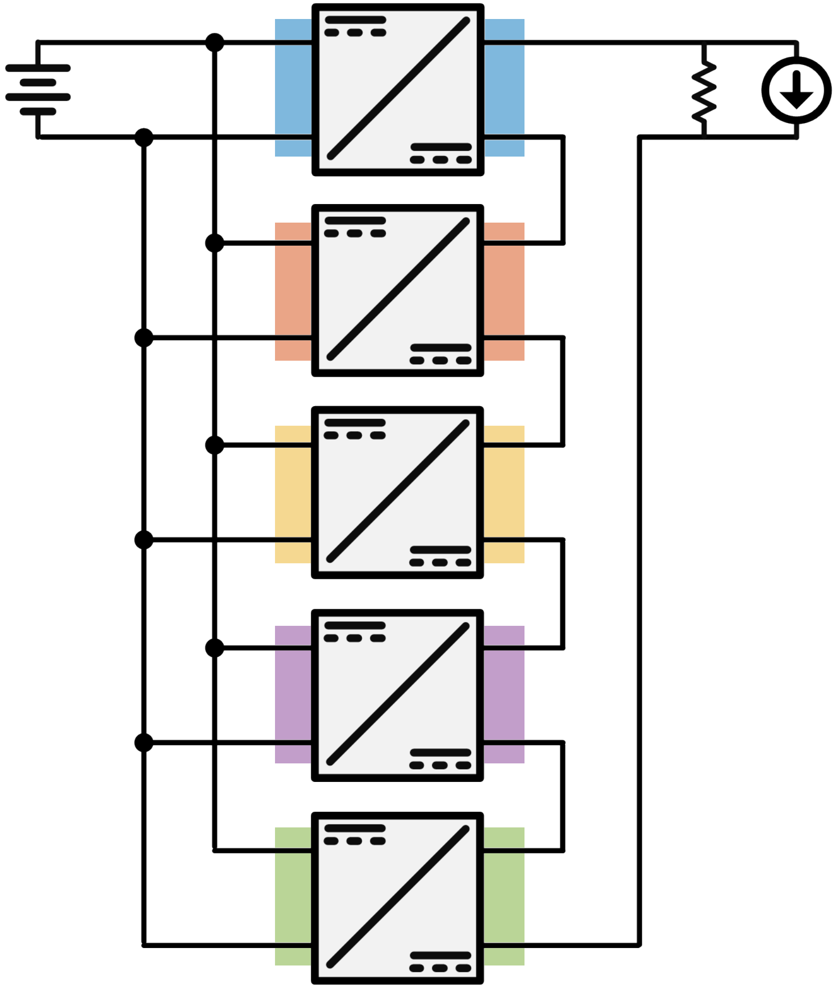
- Single input configuration
- Converters turn on sequentially, one every 100ms
- Goal is to verify voltage sharing in series outputs

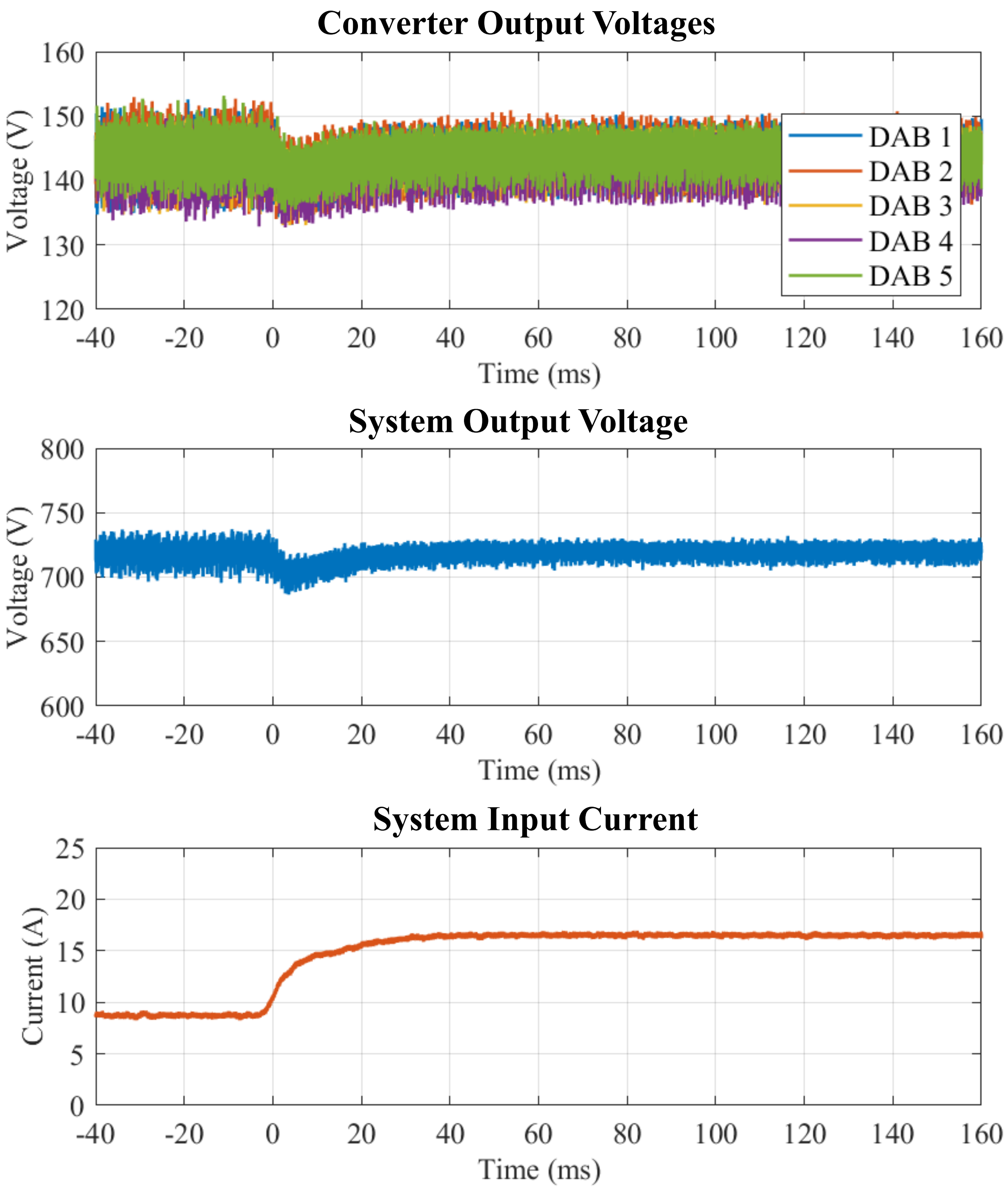




Hardware Results – Load Step

- Current load changes from 0A to 0.5A at t = 0s
- Goal is to verify response to transient disturbance, minimal cross-coupling between converter controllers





Converter Output Voltages

System Output Voltage

System Input Current

Summary and Future Work

- Existing power conversion architectures are **unable to meet the needs of next-generation energy storage systems**
- The key challenge is solving the disconnect between low-voltage/high-current battery cells and high-voltage/low current utility grids
- If a high voltage DC link can be generated, we can **draw on technologically mature medium voltage inverters** from MV drive applications
- Two solutions, both in need of further exploration:
  - High-gain DC-DC converters
  - Cascaded DC-DC converter structures
- For cascaded system architectures, there are two paths forward:
  - **Modeling and control** for storage modules with disparate power/energy ratings
  - Overcome practical barriers to **full-scale implementation**
- Goal in FY24: Scale up to medium voltage, demonstrate at 5kV

New medium voltage power electronics lab space in development, to be operational by end of FY24.

Acknowledgements

Thanks For Your Attention

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For further information, please contact:

Jake Mueller
jmuelle@sandia.gov

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