MERIT: Medium Voltage Resource Integration Technologies

Modular and Scalable Converter Development for MERIT

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Colorado Boulder Electronics Center

University of Colorado Boulder

Colorado Power Electronics Center at CU-Boulder

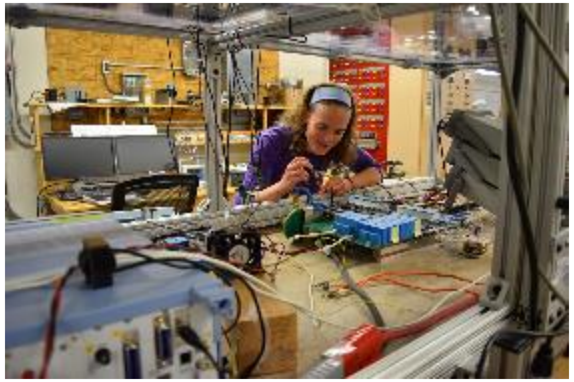
- **Power Electronics Faculty**

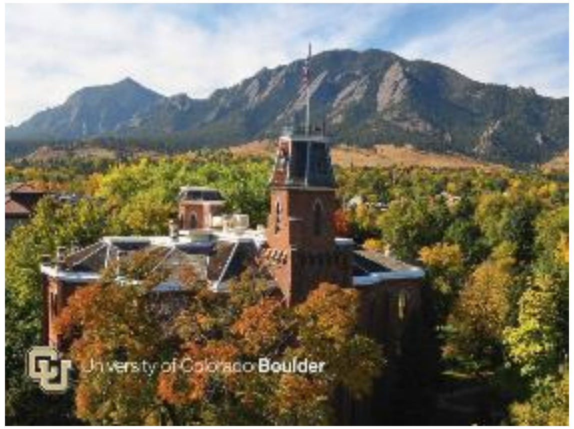
Prof. Luca Corradini

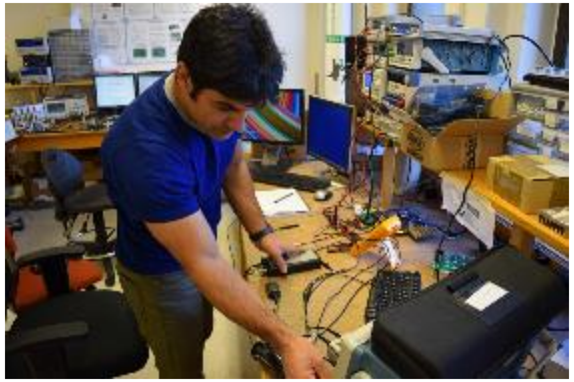
Prof. Robert Erickson

Prof. Dragan Maksimovic

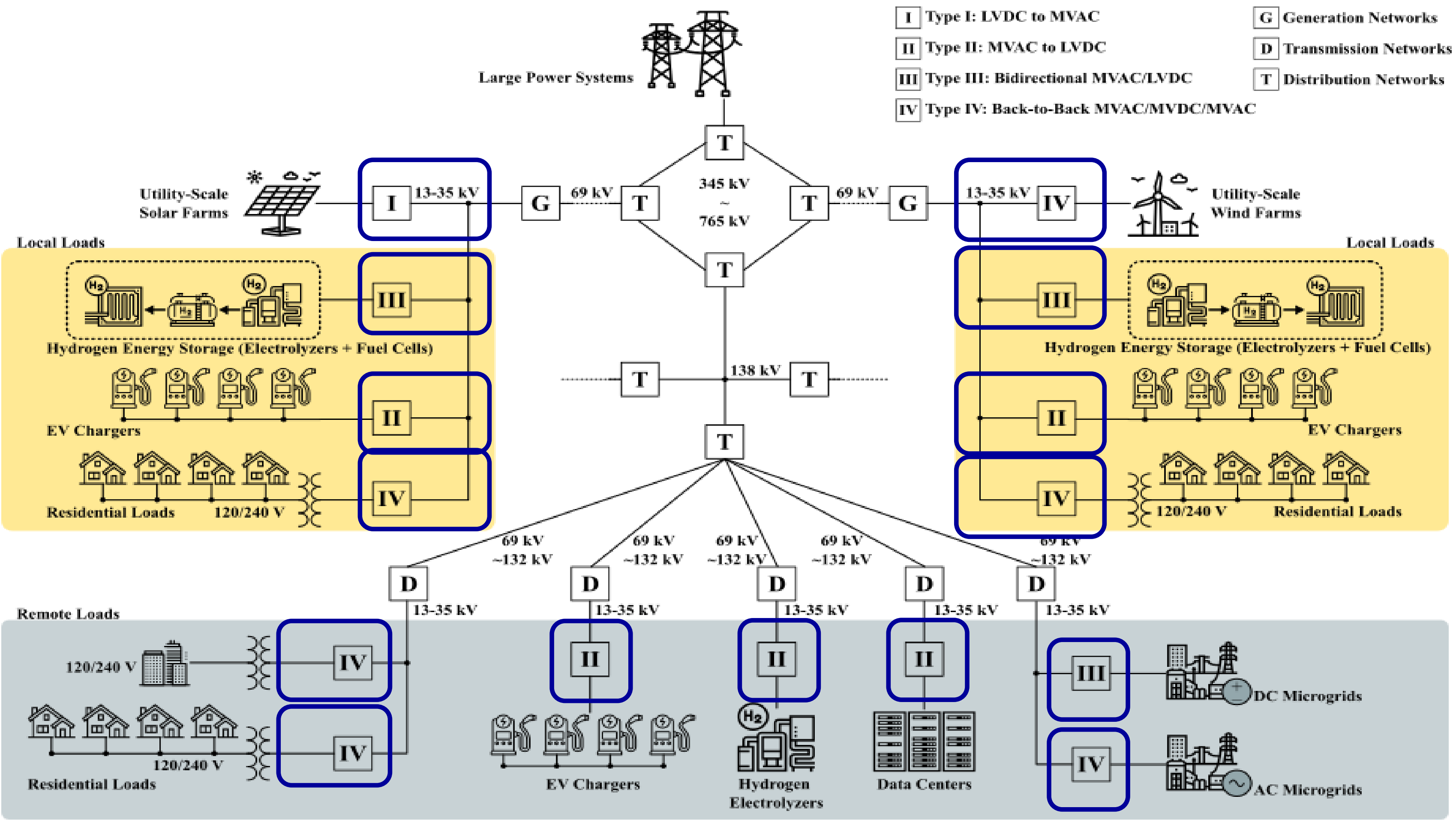
- **Comprehensive power electronics curriculum**
  - Professional MS and Traditional MS in power electronics
  - Graduate certificates in power electronics and electric drivetrain technology
  - Short courses and degree (MS-EE) on Coursera https://www.coursera.org/specializations/power-electronics
- **Research projects sponsored by industry and agencies** (DOE SETO, DOE VTO, ARPA-E, NSF, ONR, DARPA, …)
- **Collaborations with National Renewable Energy Lab (NREL)**



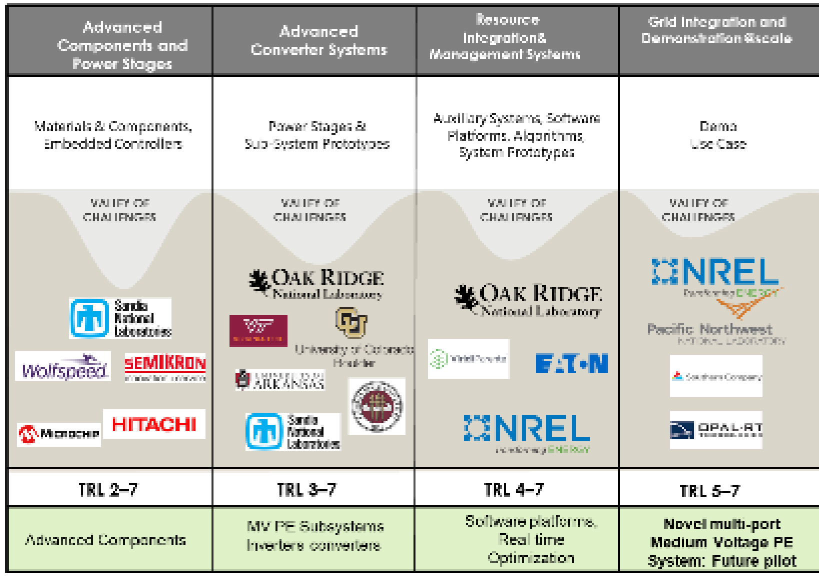




Modular and Scalable MV Power Electronics Building Blocks for Everything



- Utility-scale PV
- Wind
- Energy storage
- Ultra fast EV charging
- Electric hydrogen
- Solid-state transformers

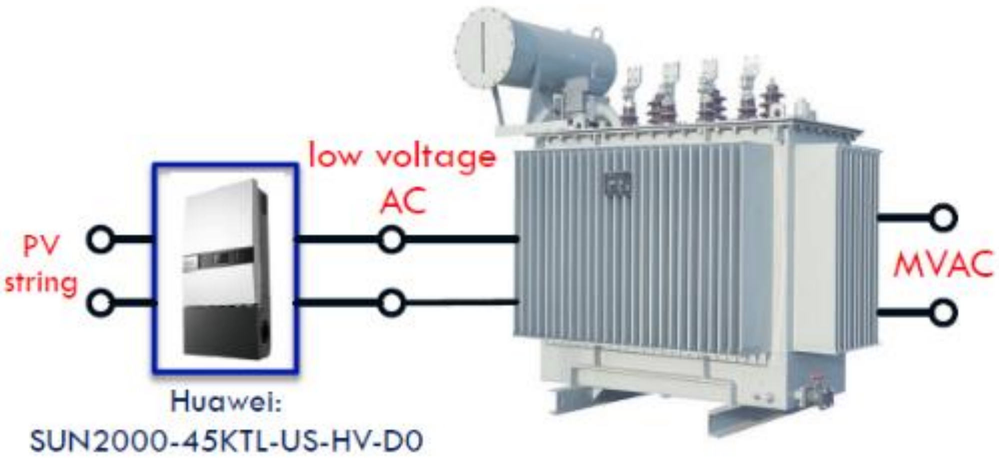


Modular Transformerless LVDC-MVAC Architecture

for Utility-Scale PV Systems, Wind Systems, Grid-Tied Storage, Ultra-Fast Charging, and Electric Hydrogen

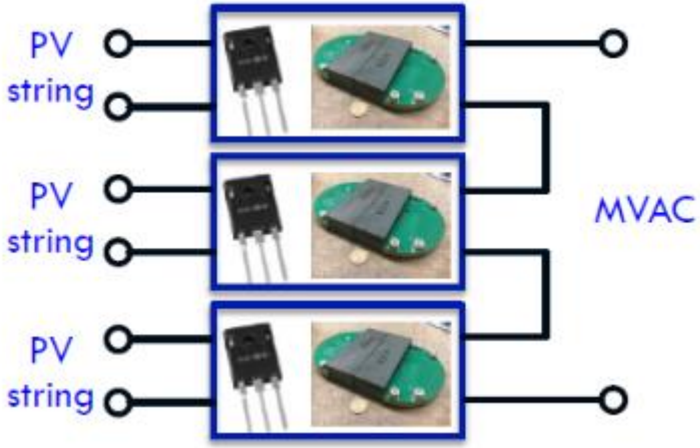
Conventional

Three-phase string inverters
+ line frequency transformers



Modular Power Electronics Building Blocks

Distributed wide-bandgap electronics
+ high frequency magnetics



4.16 kV to
34.5 kV kVac

Inverter×Transformer peak efficiency	0.983×0.99 = 97.3%	99.1%
Inverter×Transformer CEC efficiency	0.982×0.99 = 97.2%	99.0%
Inverter Capacitance	10 J/kW	1 J/kW
Inverter ac voltage	600 Vac	13.2 kV ac
Transformer needed?	Yes	No
Inverter isolated?	No	Yes

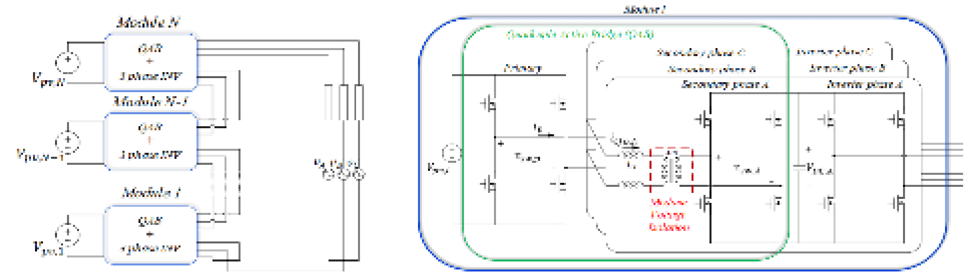
MV Converter Development and Demonstration

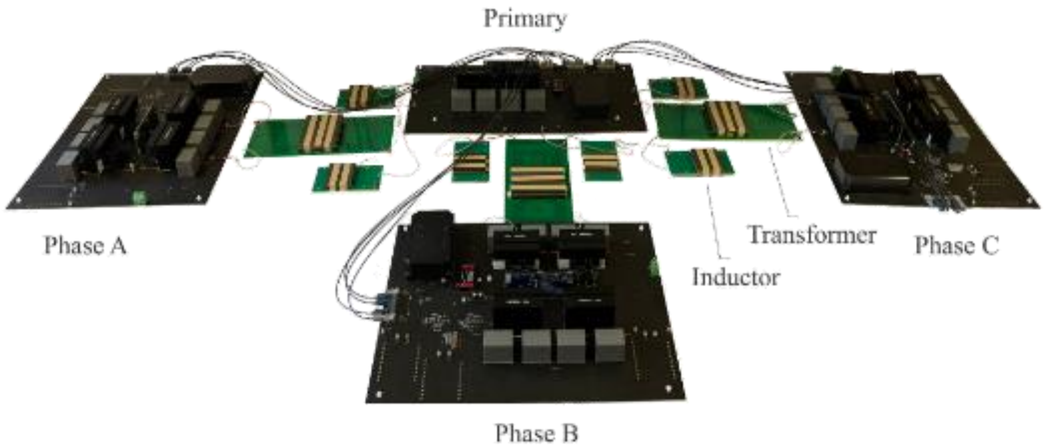
MV Converter Development for MERIT
Modular and Scalable up to 13.2kV

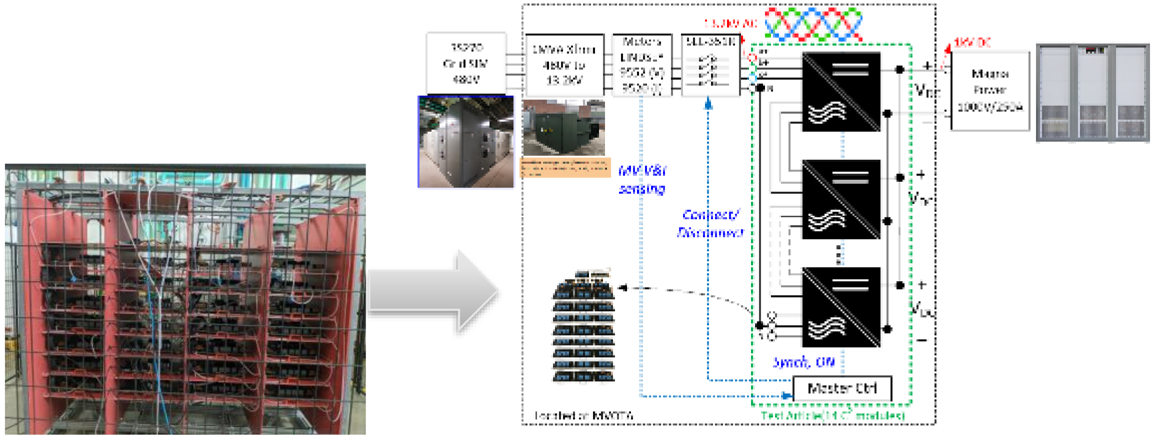
- Initial development supported by DOE SETO
- University parents: CU Boulder and UT Austin
- Circuit + controller modules
  - Modular & Stackable 3ph AC-to-DC PEBB
  - MV isolation through HF Xfmr
  - Usable for a variety of cases: series or parallel, or individual at each ac/dc side
- Use cases: MV Hydrogen, MV EV XFC, PV, Wind…

Focus

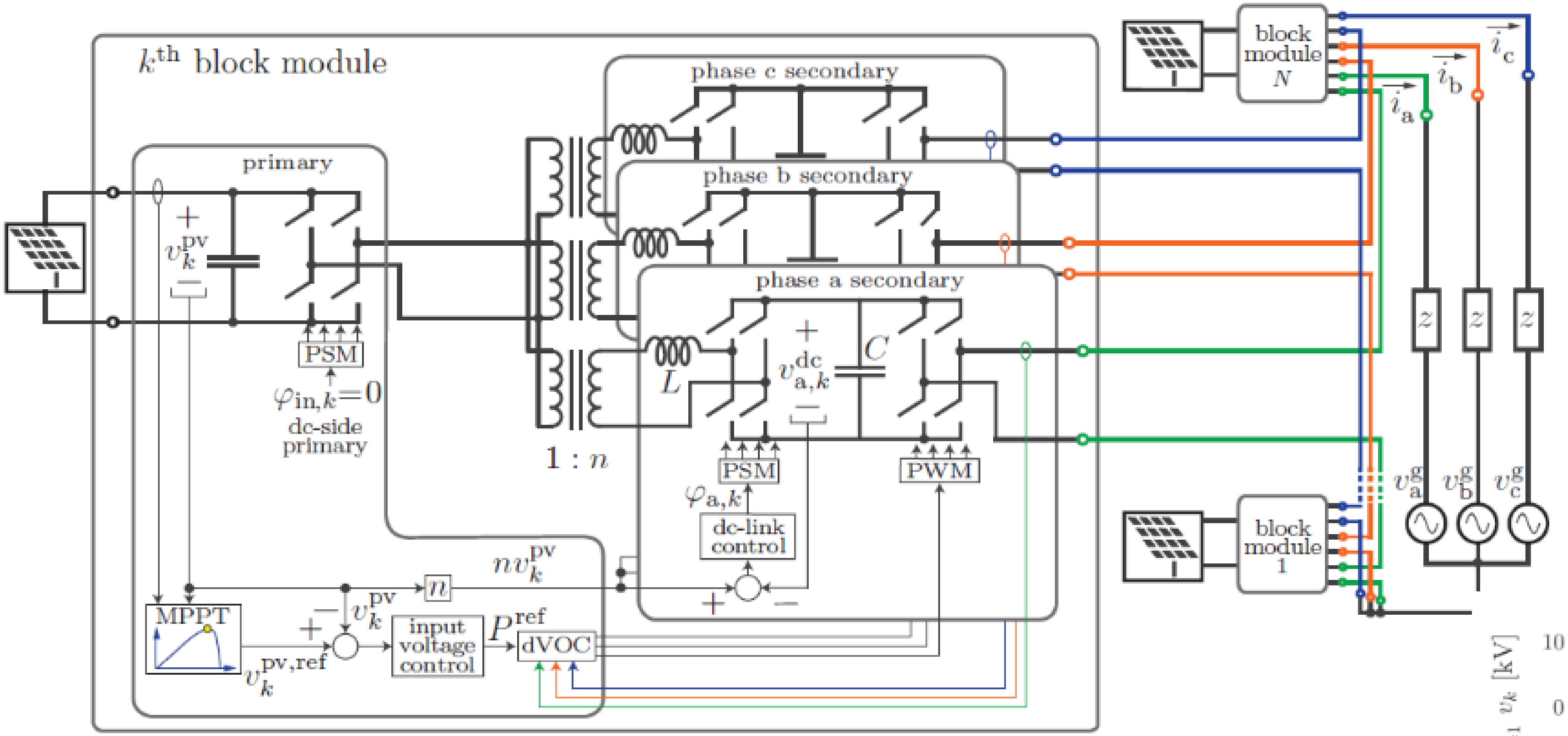
- **Identify** promising applications, **develop** controls and hardware, and **validate** in real-time simulation, CHIL and PHIL



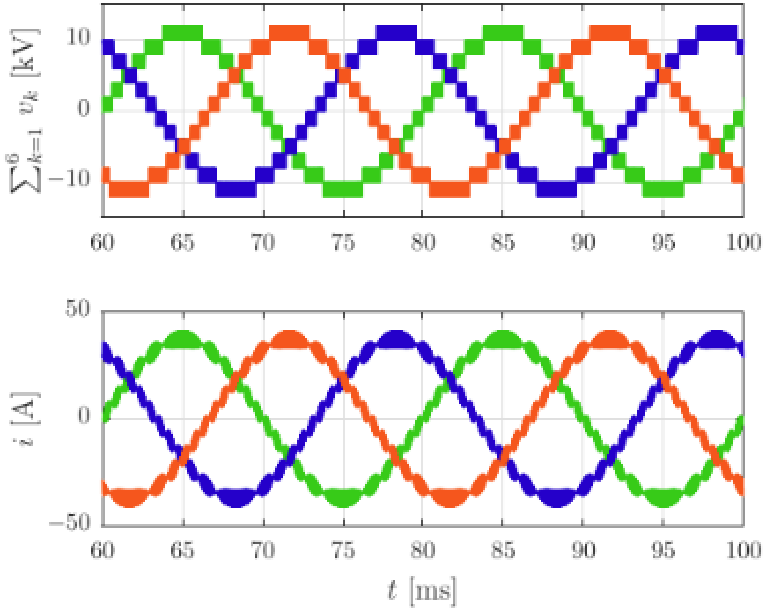




MV PEBB Converter Module



- Inverters/rectifier modules stacked in series
- Interleaved to synthesize multi-level voltage output and minimize output current ripple
- Enable the use of 1.2 kV, 1.7 kV, or 3.3 kV SiC MOSFETs



- Compact high frequency transformers provide electrical isolation
- SiC MOSFETs are soft switched to minimize switching losses

TEXAS The University of Texas at Austin

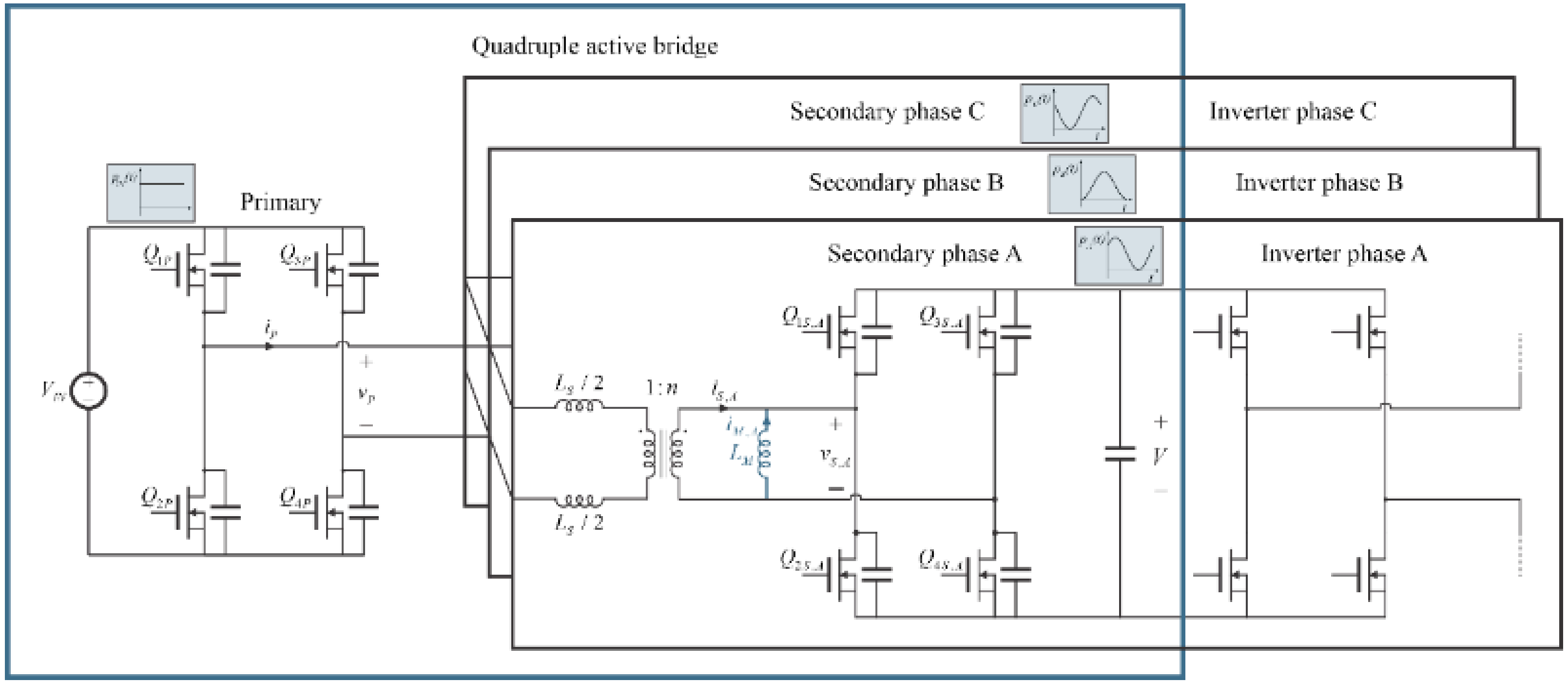
University of Colorado Boulder

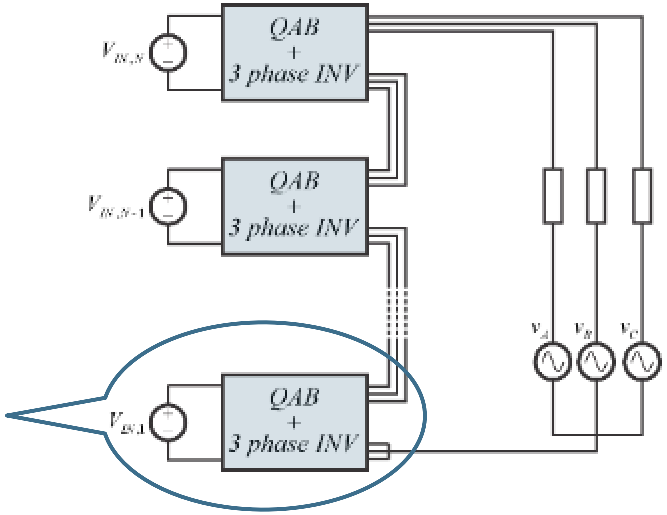
NREL NATIONAL RENEWABLE ENERGY LABORATORY

SOLAR ENERGY TECHNOLOGIES OFFICE U.S. Department Of Energy

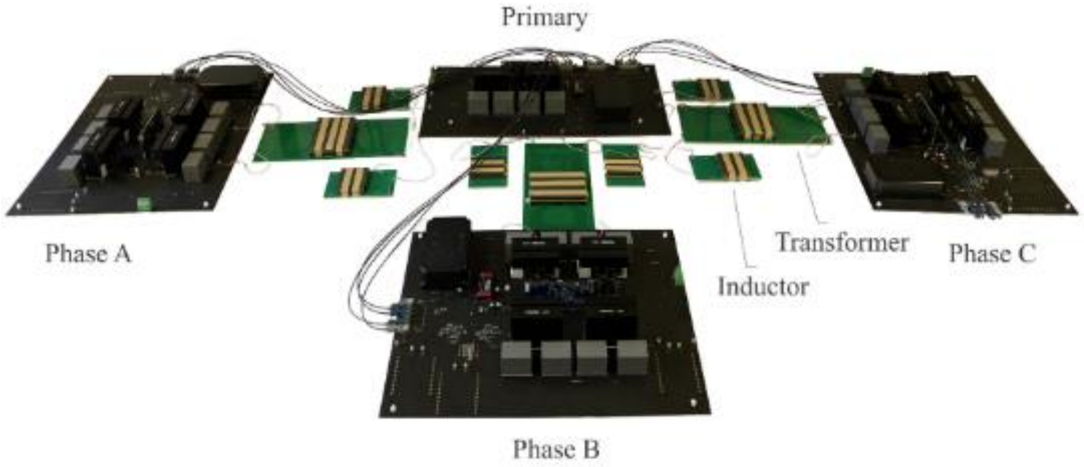
Initial development sponsored by DOE SETO

Initial (1 kV, 10 kW) Prototype Module Realization

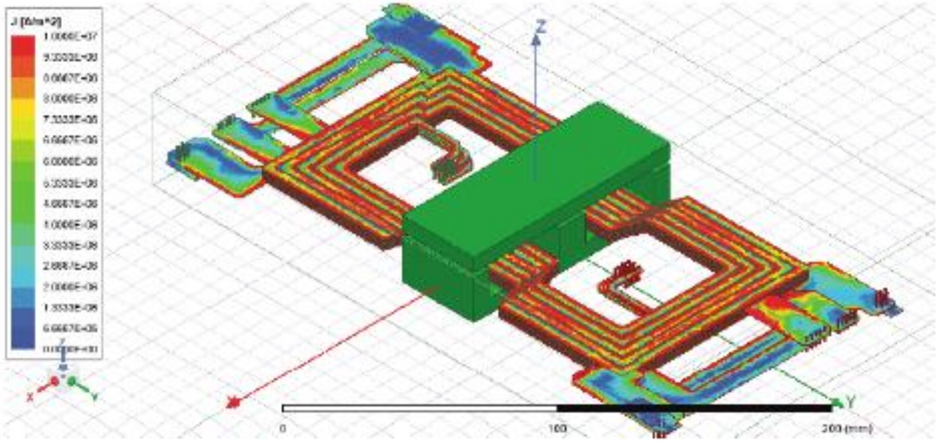


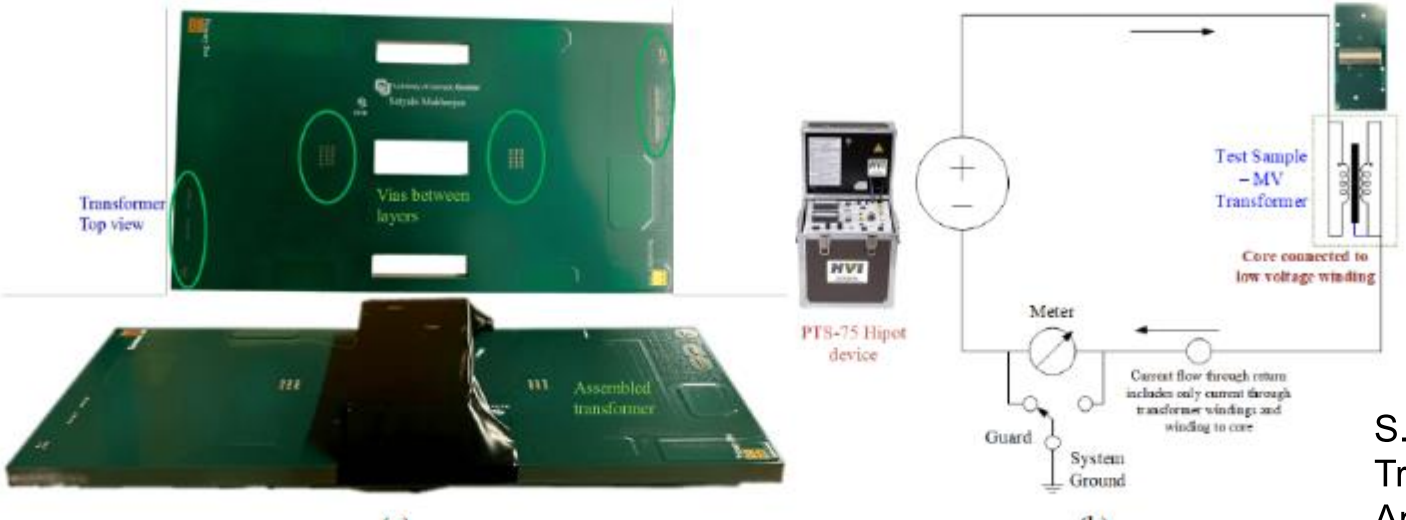


- SiC MOSFET based, soft switching quadruple active bridge followed by 3 stackable inverter/rectifier bridges
- High-frequency planar isolation transformers with medium-voltage isolation capability
- Decentralized controls



Planar Transformer with MV Isolation Capability: Path to High-Density MV PEBB



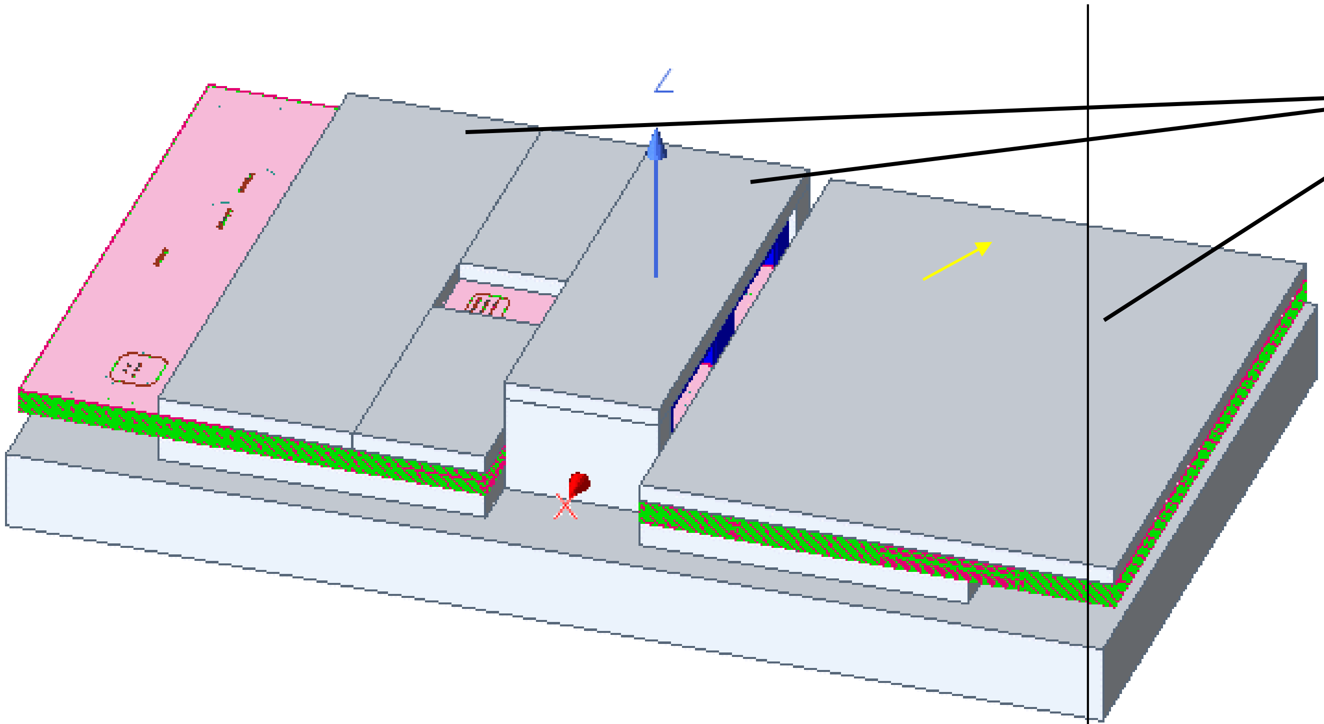


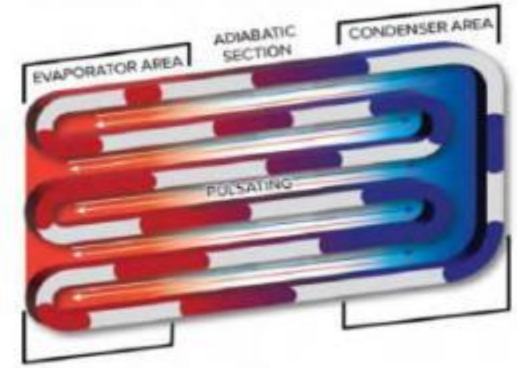
(a) (b)

- Interleaved PCB winding layers to minimize ac loss
- Polyimide (Panasonic Felios RF775), 7 kV/mil between copper layers
- 26 kV isolation capability
- 200 kHz switching frequency in a 1:1 dual-active bridge stage

S. Mukherjee et al., "A High-Frequency Planar Transformer with Medium-Voltage Isolation," 2021 IEEE Applied Power Electronics Conference and Exposition (APEC), Phoenix, AZ, USA, 2021, pp. 2065-2070.

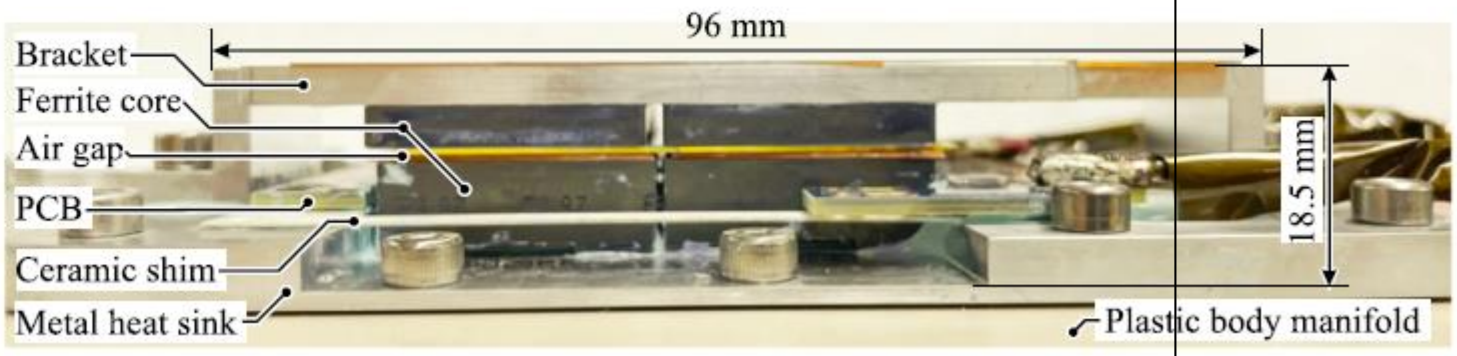
Planar Transformer with MV Isolation Capability: Path to High-Density MV PEBB





Work in progress:

- Integration of thermal management using **pulsating heat pumps** (PHP)
- Compact enclosure with embedded isolation and thermal management to enable high-density scaling of MV PEBB

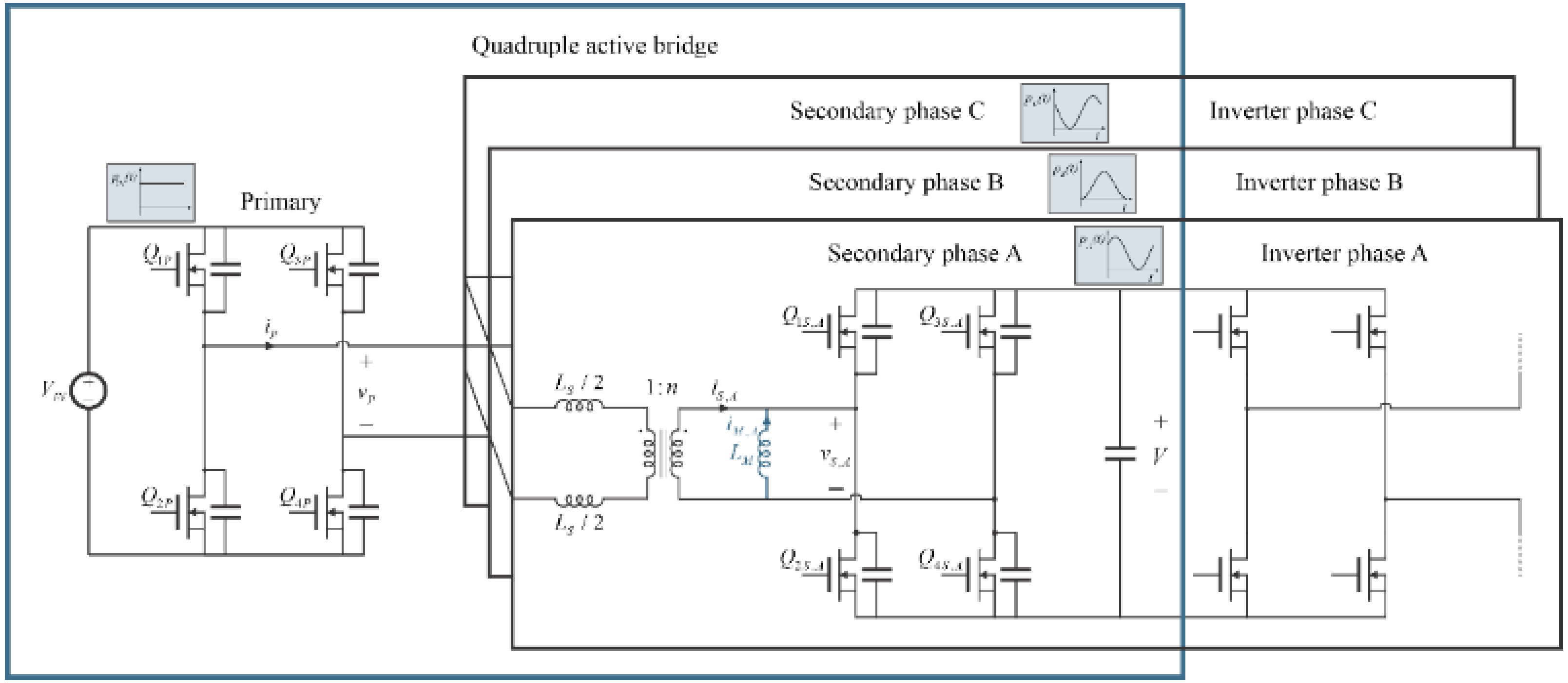


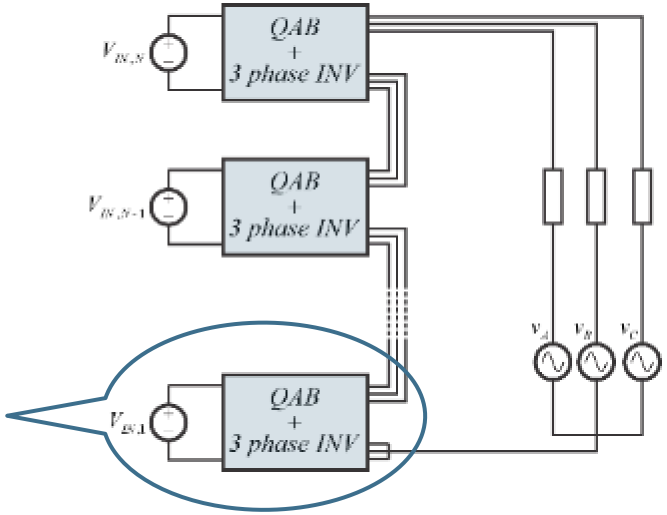
ACT | ADVANCED COOLING TECHNOLOGIES

University of Colorado Boulder

DOE VTO Phase II SBIR

Initial (1 kV, 10 kW) Prototype Module Realization





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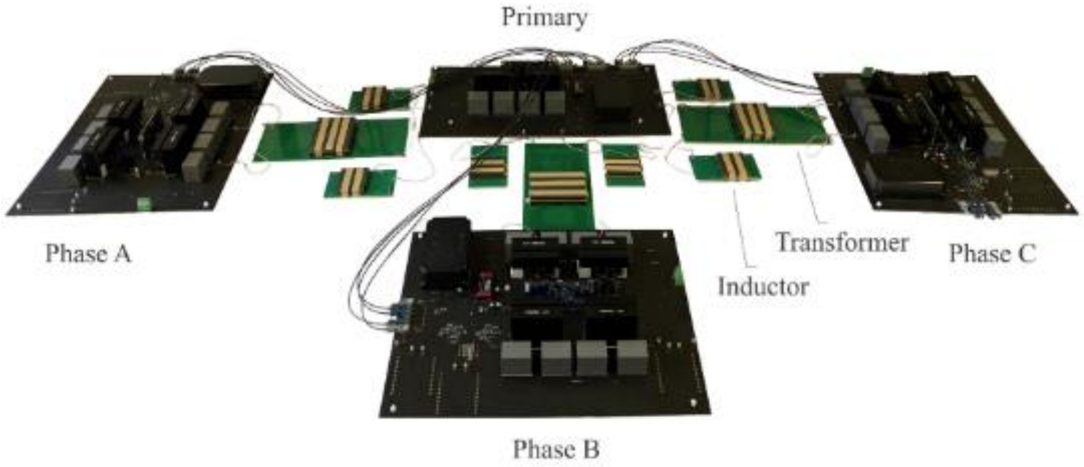
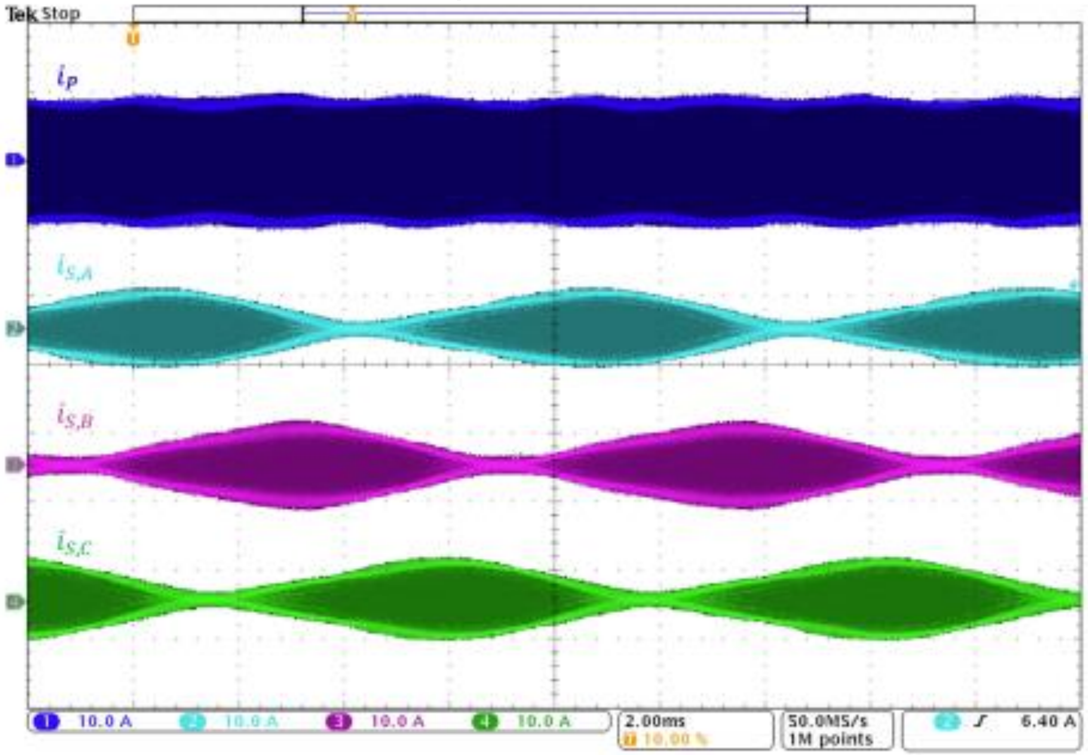
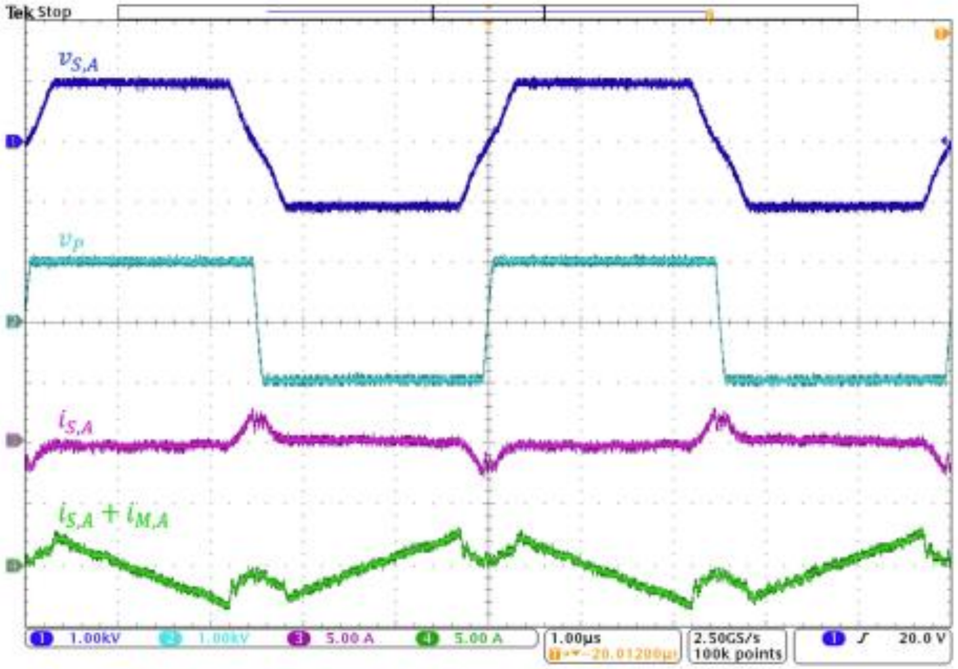


MV PEBB Prototype Hardware Verification: Operating Waveforms

QAB primary and secondary currents,
ac line period scale



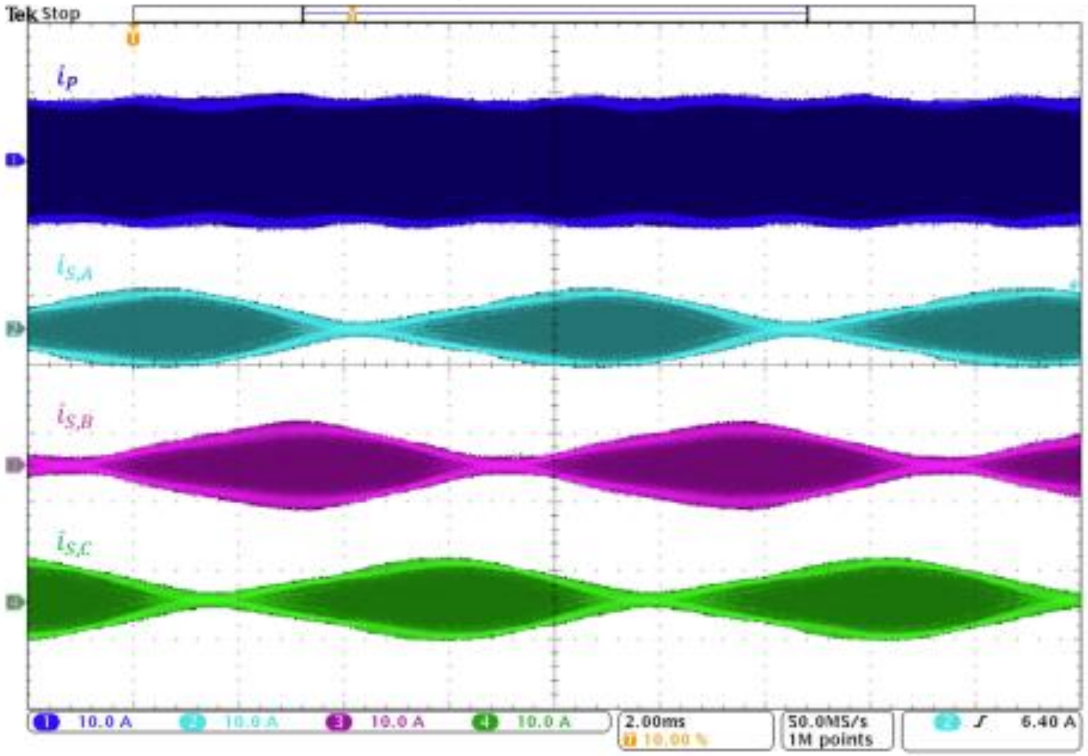
QAB primary and secondary voltages
and currents at zero power crossing, switching-period scale



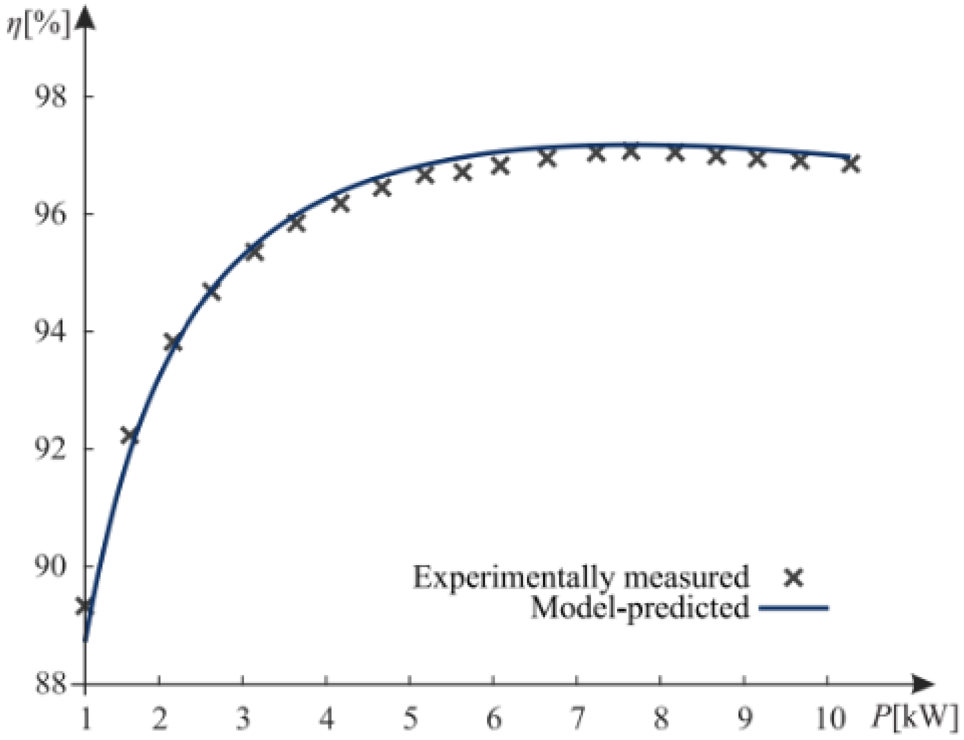
B. Majmunović, S. Mukherjee, T. Martin, R. Mallik, S. Dutta, G.S. Seo, B. Johnson, D. Maksimovic, “1 kV, 10-kW SiC-Based Quadruple Active Bridge DCX Stage in a DC to Three-Phase AC Module for Medium-Voltage Grid Integration,” in IEEE Transactions on Power Electronics, vol. 37, no. 12, pp. 14631-14646, Dec. 2022.

MV PEBB Prototype Hardware Verification: Module Efficiency

QAB primary and secondary currents,
ac line period scale



Efficiency



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MV Converter Development and Demo – Future Works

MVAC-to-LVDC PEBB Module-Level Developments

- Decentralized interleaving
- Decentralized power sharing and ac-grid-level synchronization
- Integration of energy buffering and planar transformer
- Power density and efficiency improvements

MVAC-to-LVDC System Developments and Validation

- System-level modeling and simulations
- Grid support functions
- Controller Hardware-in-the-loop validation
- Power Hardware-in-the-loop validation

Use cases: XFC, Hydrogen, PV, …