NEXT-GENERATION MODULAR FLEXIBLE LOW-COST SILICON CARBIDE (SIC)-BASED HIGH-FREQUENCY-LINK TRANSFORMER

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Team Members: Dr. Juan Balda, University of Arkansas

Acknowledgement: A. Pereira, F. Palma, K.A. Dodrill, and E. Chambers (DOE)

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Project Summary

- Background/Problems Being Addressed

❑ In general,
- ❖ LPTs are not interchangeable with each other
- ❖ Incur high costs due to reduced unit volume
- ❖ Prohibit extensive spare inventories
- ❖ Are manufactured for individual design (on an average only 1.3 LPTs are manufactured)
- ❖ Are reaching their end of service lives; loss of plurality of such LPTs, that form the backbone of U.S. power grid, will clearly run into the problem of energy security
- ❖ Involve a complex process of procurement (typically 20+ months) and manufacturing and requires prequalification of manufacturers, a competitive bidding process, the purchase of raw materials, and special modes of transportation due to its size, weight

❑ Thus, there is an opportunity for flexible and adaptable LPT designs. However, following challenges with 60-Hz LPT remain:
- ❖ LPT can cost millions of dollars and weigh in multiple tons;
- ❖ Price and volatility of copper and steel that account for over 50% of the cost of an LPT and affect the performance of the LPT, has affected the manufacturing conditions and procurement strategy for LPTs.

- *Overall Objectives*

❑ *The project research objectives were to provide an innovative HFL design for LPTs that are more compact, light-weight, modular, flexible, economical, and adaptable than current LPT designs and help create greater LPT design standardization to increase grid resilience in the event of the loss of one or more LPTs. Research efforts focused on developing a lab-scale prototype (100 kVA) that demonstrated proof-of-concept and allows for performance evaluation of the prototype.*

❑ *The project specific objectives to achieve the stated objectives noted above included the following: a) to designing, fabricating, and testing a 100-kVA module (input/output voltages: 600V/400V (RMS); output frequency: 60 Hz; device SiC BDV: 1.7 kV) for a HFL (i.e., 20 kHz) LPT; and b) subsequently, demonstrated a cascaded multi-HFL-LPT module for three-phase high-power operation.*

❑ *The HFL-LPT is perceived as an alternative to, or replacement for, conventional low-frequency (60 Hz) LPTs by potentially addressing some technical limitations of conventional low frequency LPTs. This includes providing a reduction in size and weight thereby making the HFL-LPT easier to transport. These characteristics could help it become a replacement flexible transformer for existing LPT installations.*

The Numbers

- DOE PROGRAM OFFICE:
  OE – Transformer Resilience and Advanced Components (TRAC)
- FUNDING OPPORTUNITY:
  DE-OE0000909
- LOCATION:
  Hoffman Estates, IL
- PROJECT TERM:
  09/23/2019 to 11/30/2022 (with NCE)
- PROJECT STATUS:
  Completed
- AWARD AMOUNT (DOE CONTRIBUTION):
  $1,499,545
- AWARDEE CONTRIBUTION (COST SHARE):
  $375,361.00
- PARTNERS:
  NextWatt LLC (PRIME)
  University of Arkansas (Subawardee)

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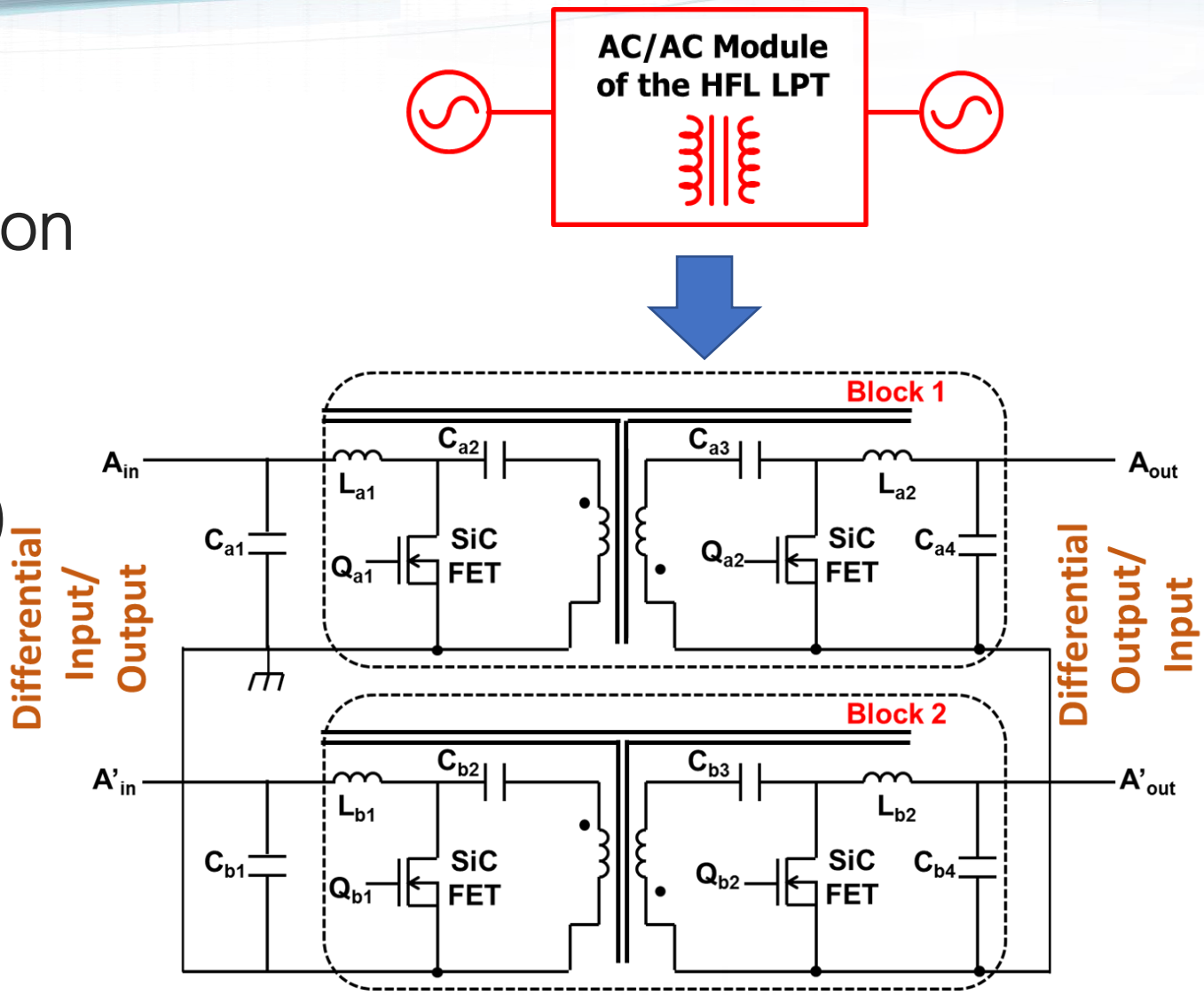
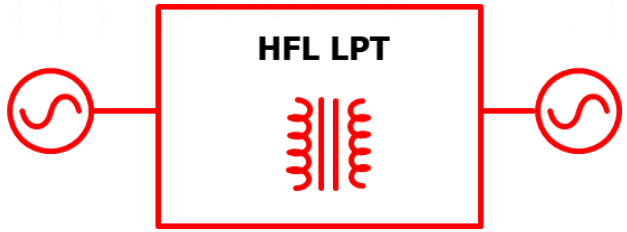
Technical Approach: *Fundamental Module*

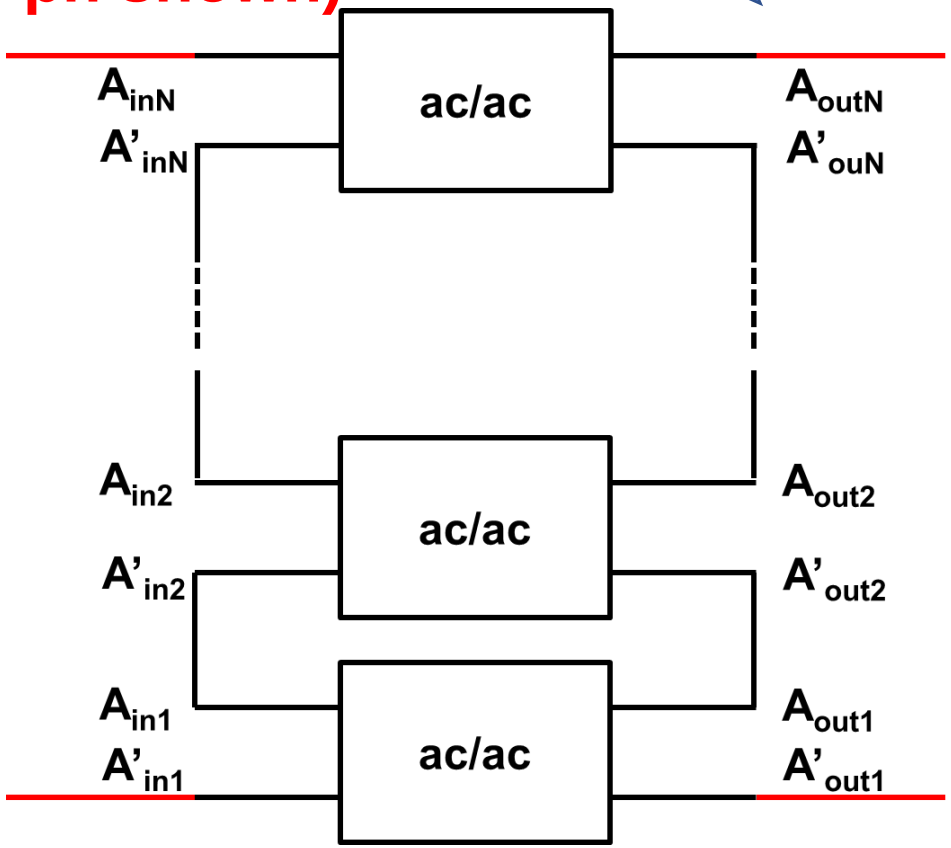
- True single-stage power conversion
- Reduced device count
- Integrated magnetics
- Soft switching (all ver. not shown)
- Up/down capability
- Input-output continuous
- EMI filtering reduced
- Multi-functional



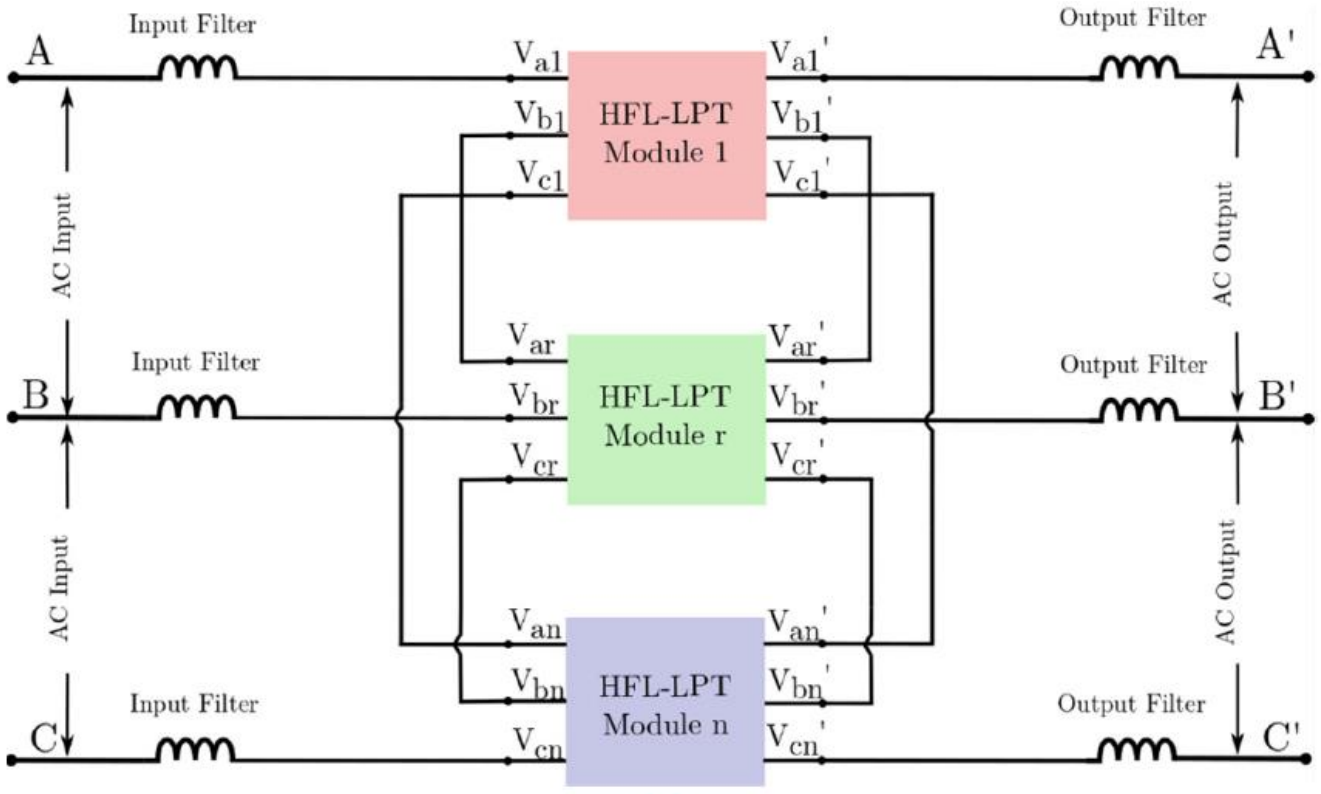
Technical Approach: *Voltage/Power Scalability*



3x1-ph
(1-ph shown)



3-ph



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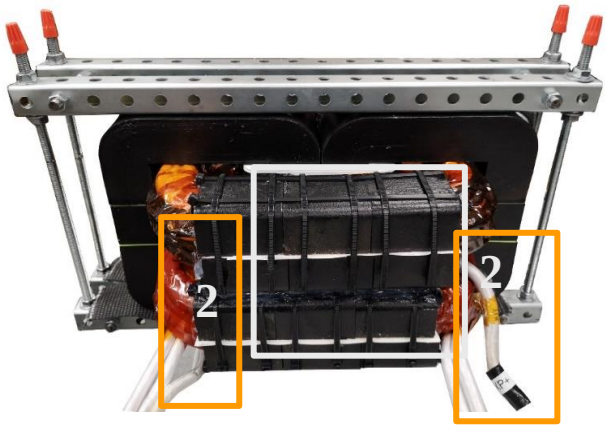
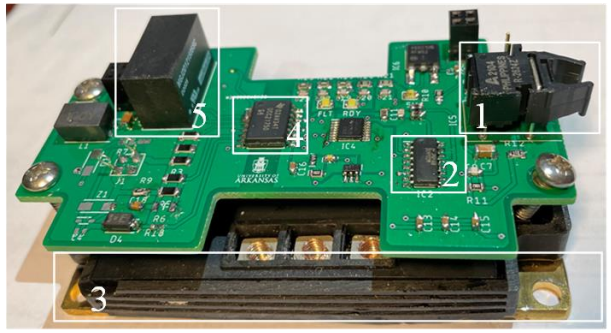
Technical Approach: *Design and Fabrication*

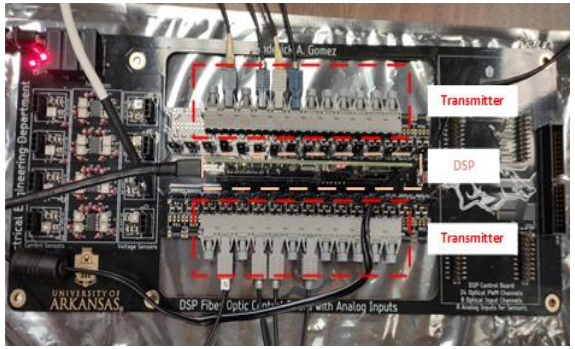
Nanocrystalline Core based HFL-LPT Integrated Magnetics



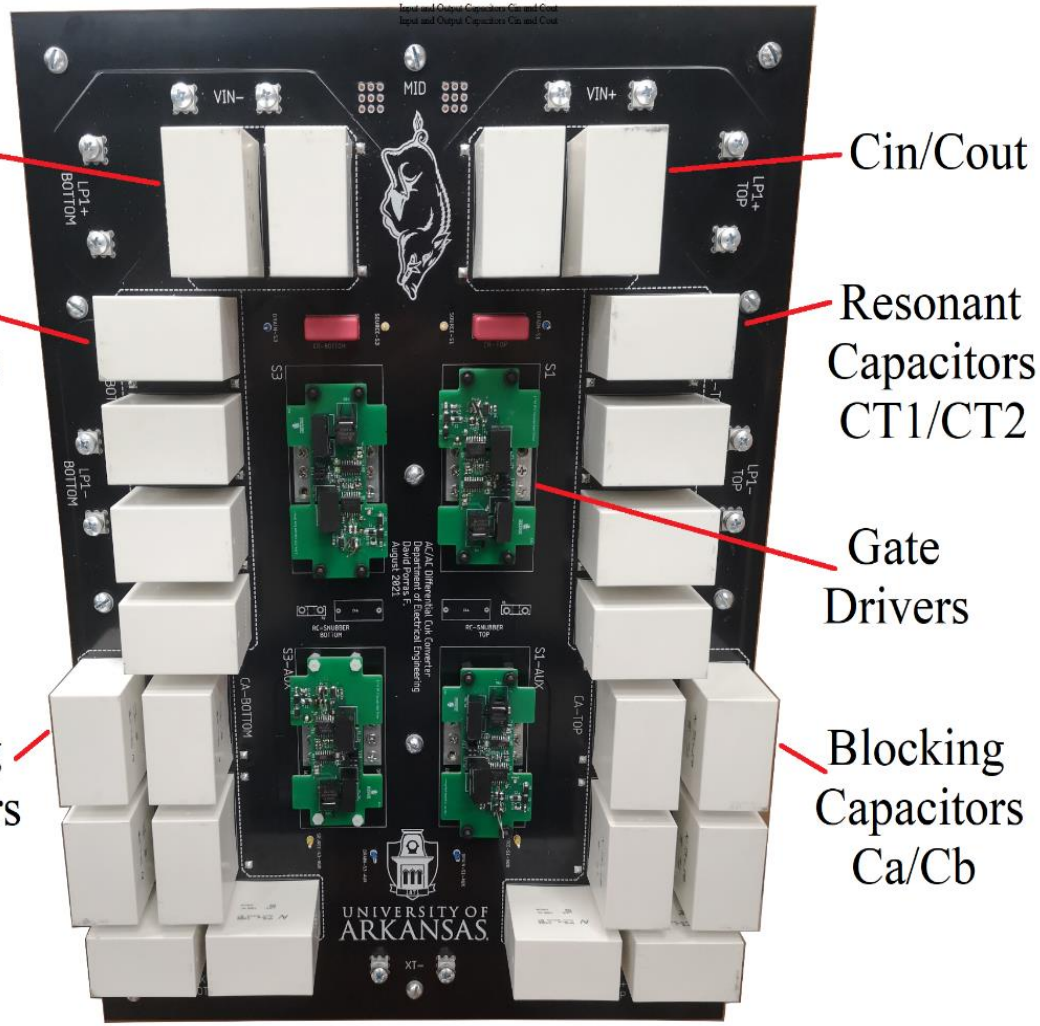
SiC FET Gate Driver for HFL-LPT Module



Fiber-Optics and DSP-based HFL-LPT Module Controller



1-ph AC/AC Module



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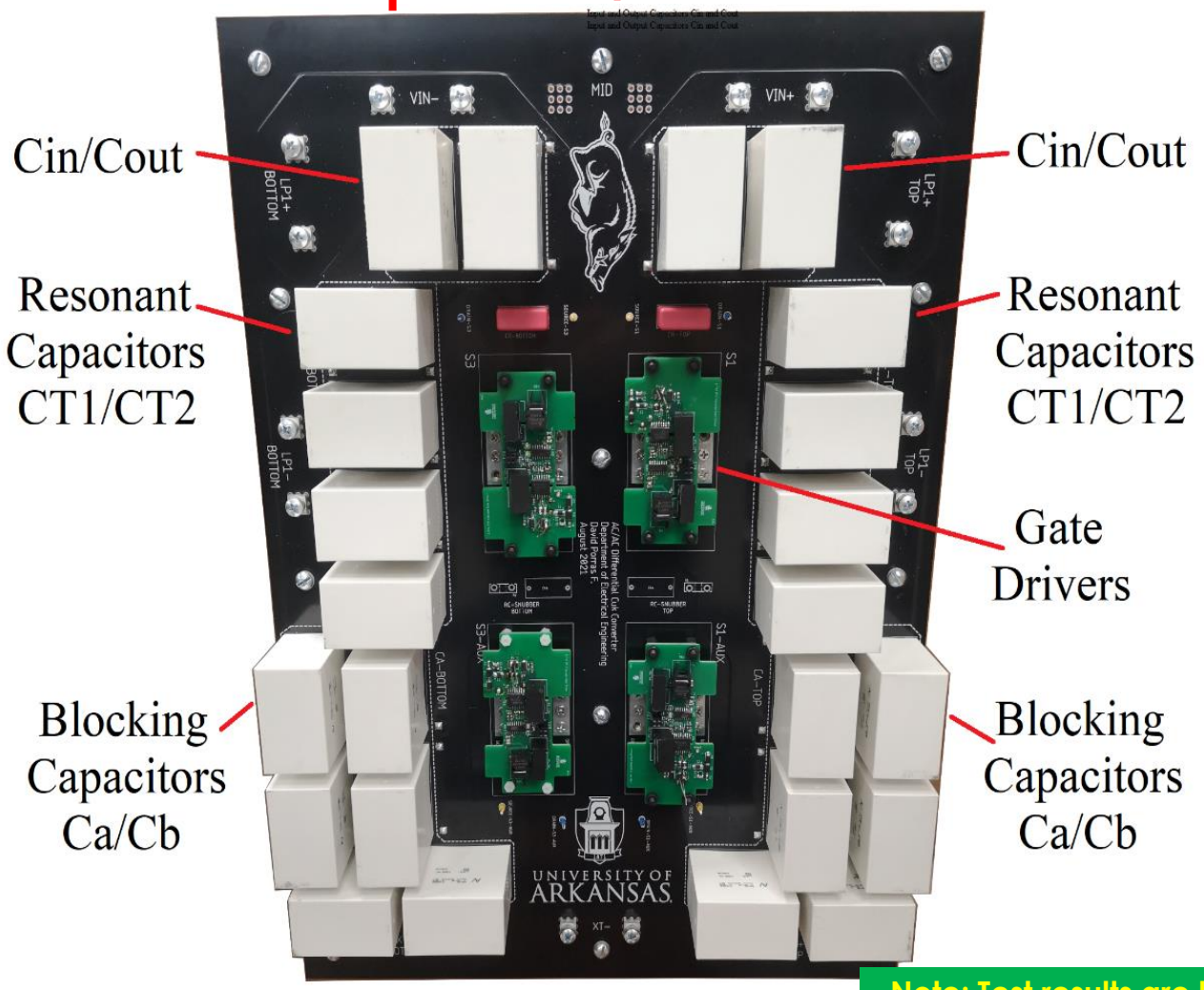
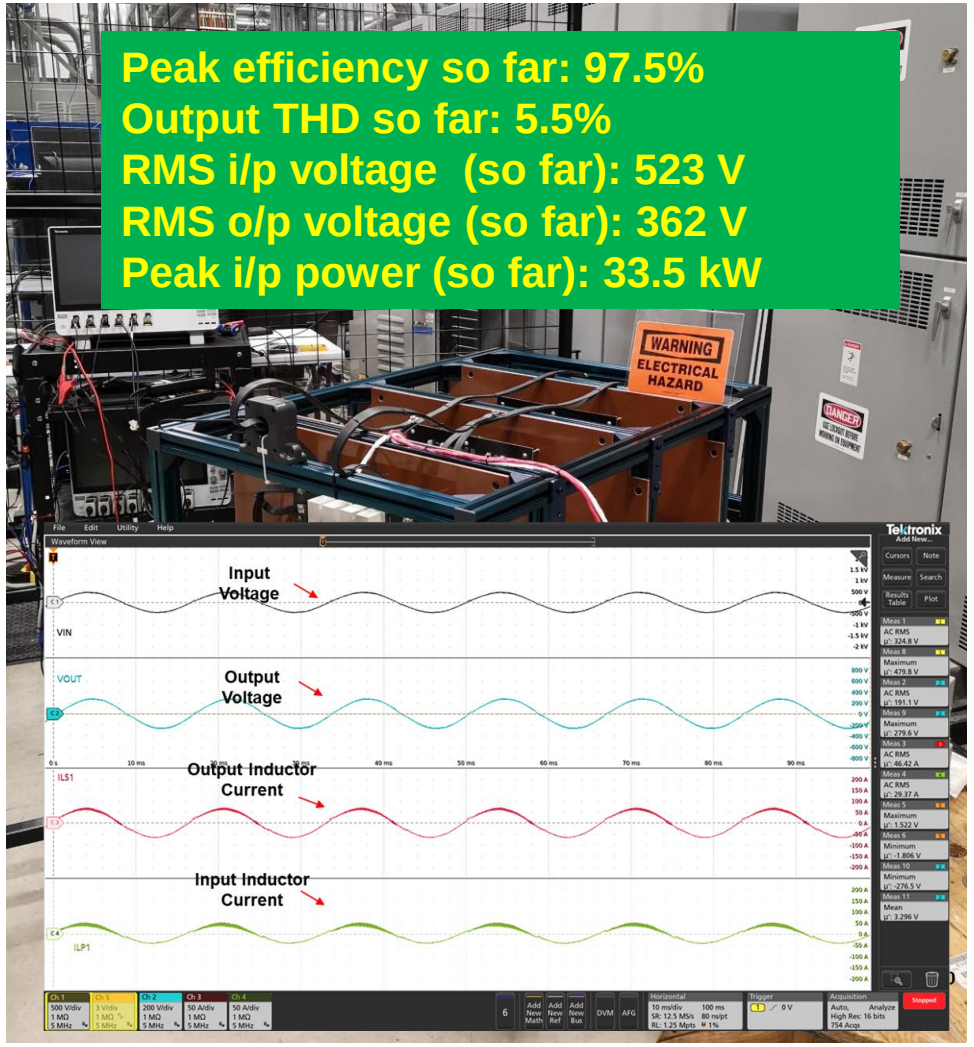
Technical Approach: *Design and Fabrication (2)*

1-ph: 1 AC/AC Module



1-ph Test Setup



Note: Test results are based primarily on non-optimized and not custom-made but commercially-available components. Also, in some cases, input voltage had harmonics.

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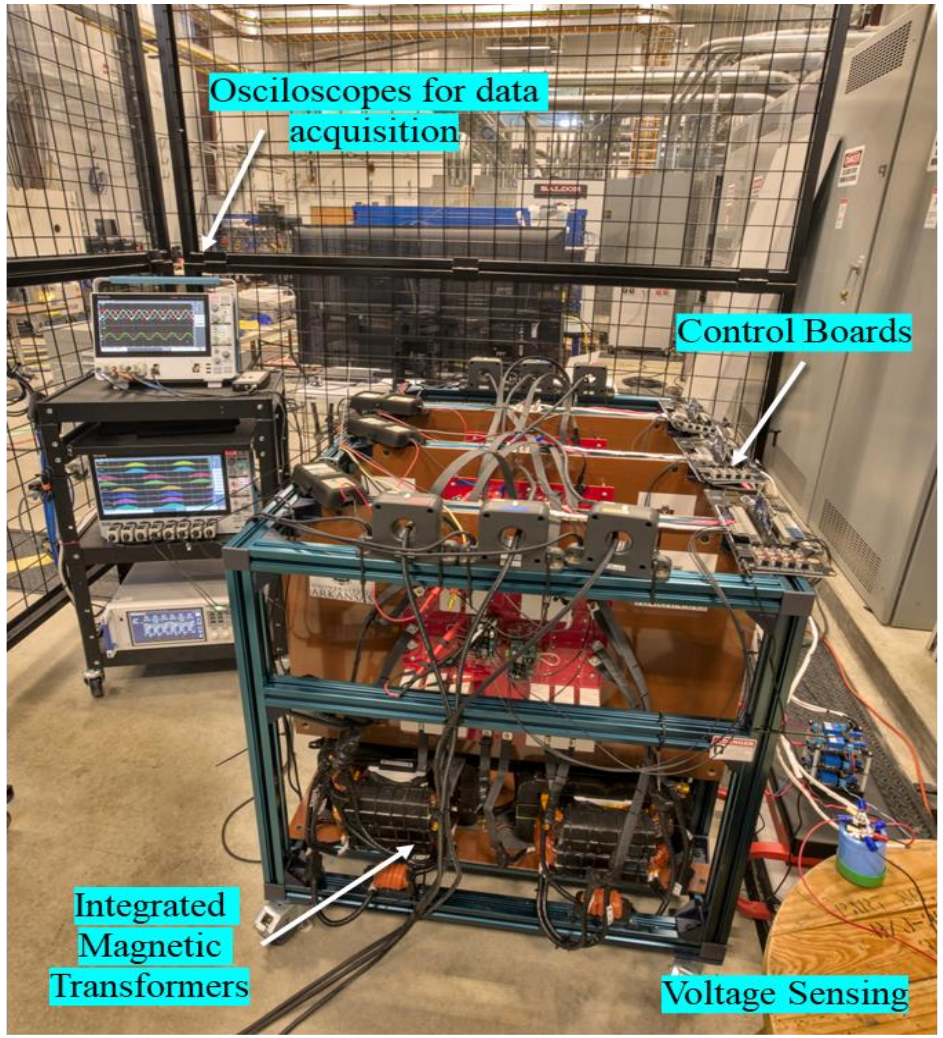
Technical Approach: *Design and Fabrication (3)*

1-ph

3-ph



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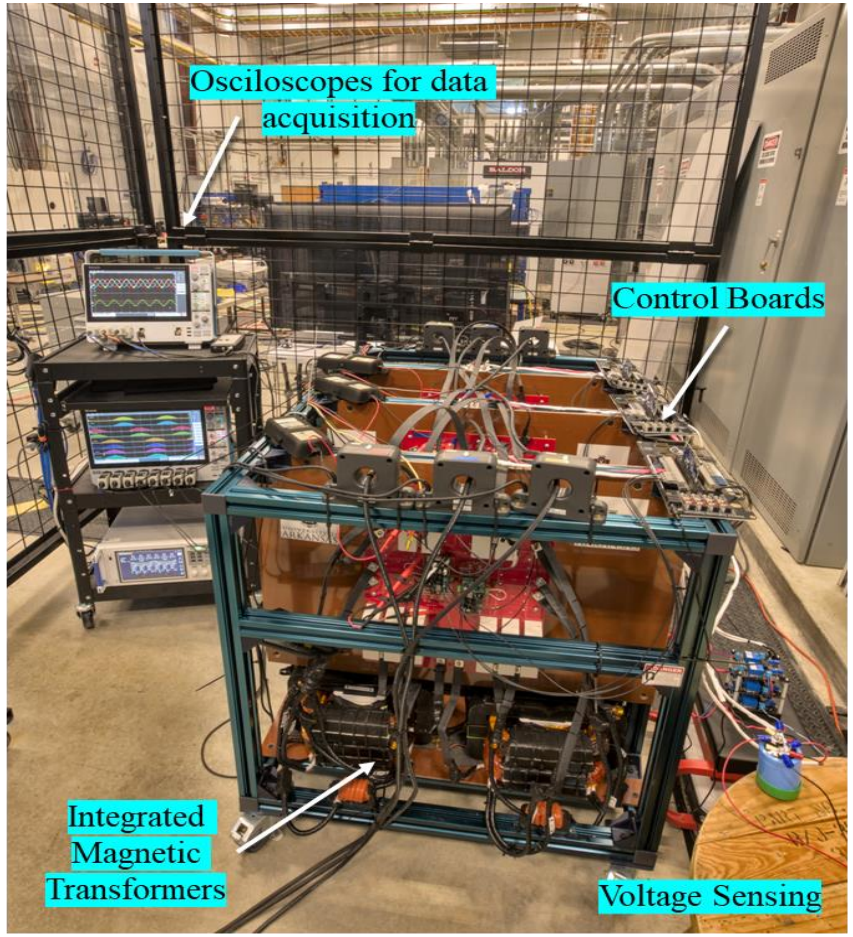
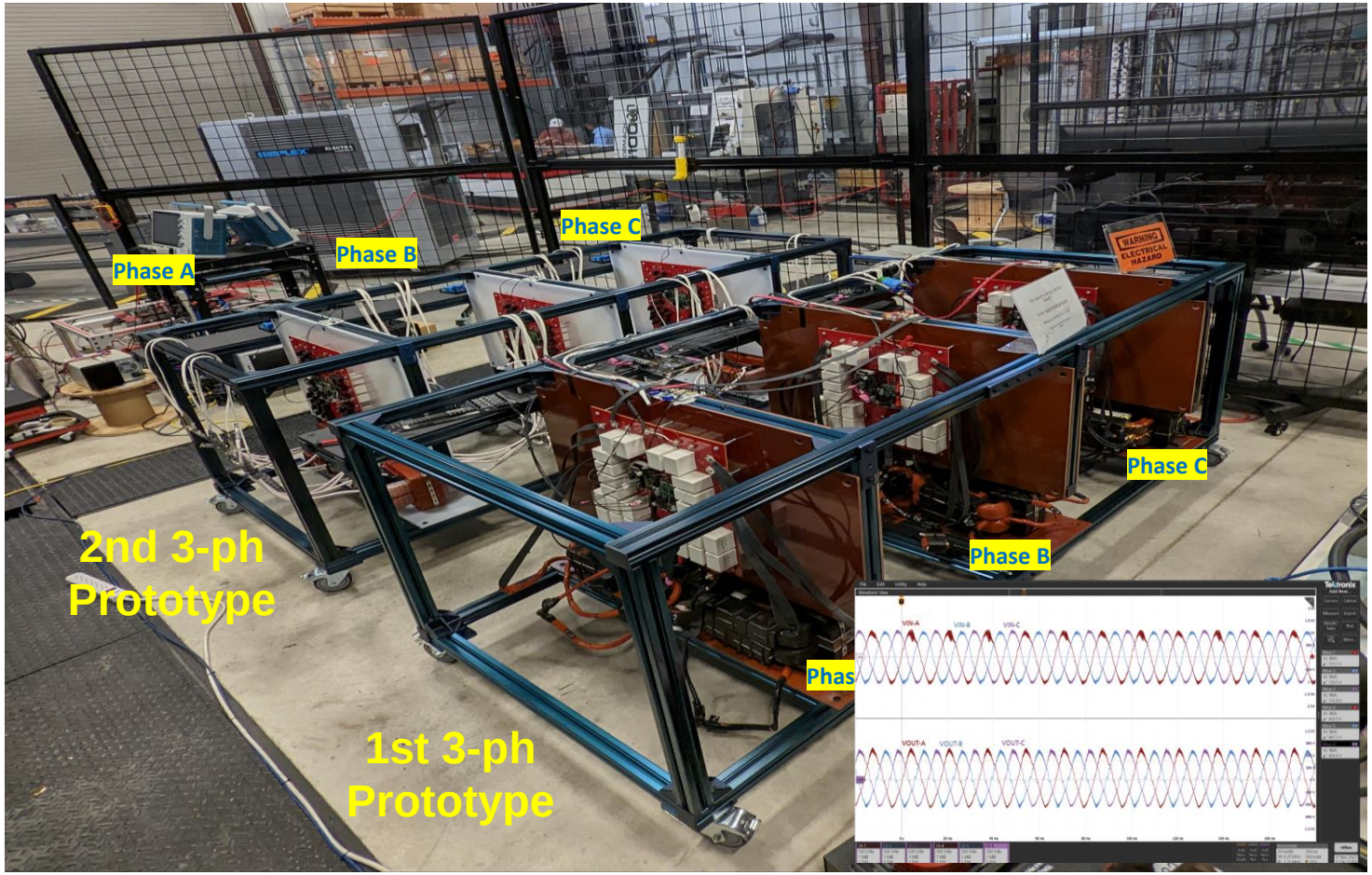
Technical Approach: *Design and Fabrication (4)*

3-ph



Cascaded 3-ph



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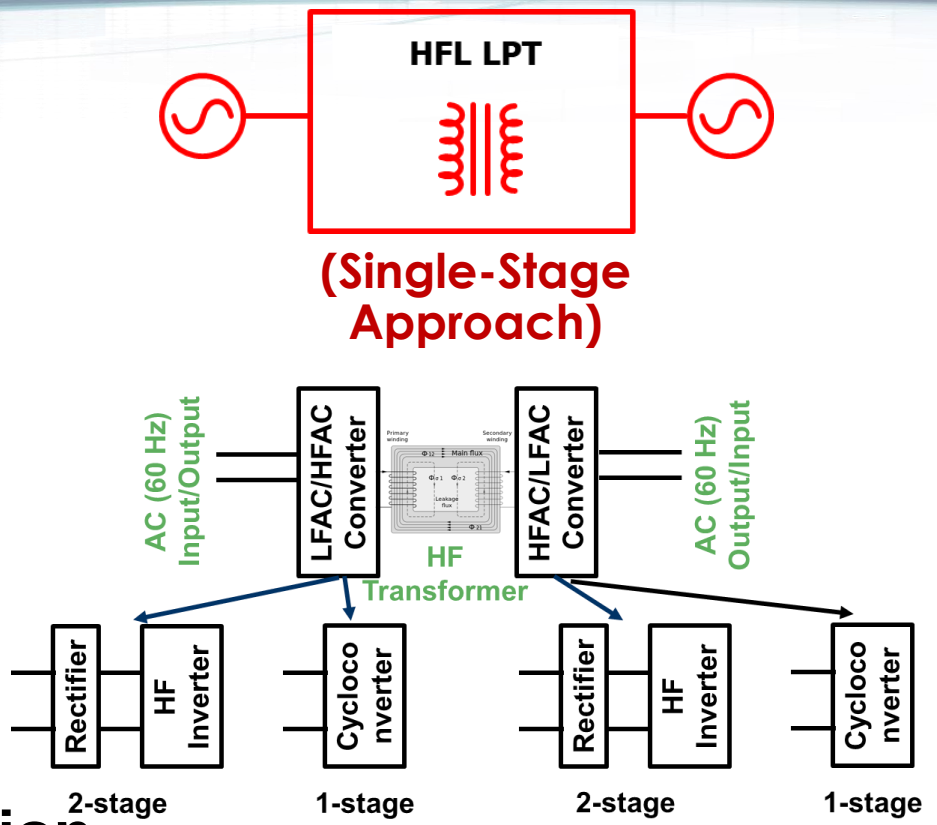
Accomplishments

- **Demonstrated successfully to the U.S. DOE, the operation of the new solid-state-transformer (SST) power-conversion system. This include the following:**
  - **HF integrated magnetics based on nanocrystalline core**
  - **Loss mitigation mechanism for SiC FETs**
  - **Digital control mechanism**
  - **Operation and validation of medium frequency AC/AC module (rated 35 kW)**
  - **Operation and validation of 3x1-ph HFL-LPT (rated 105 kW)**
  - **Operation and validation of 2 cascaded 3x1-ph HFL-LPTs (rated 210 kW)**
  - **Detailed reporting to the U.S. DOE**

- **A new US patent awarded with additional international patents pending**

Impact/Commercialization

- List of some HFL-LPT innovations:
  - A single-stage compact and efficient SiC AC/AC module
  - Modularly scalable for higher voltage and power yielding flexibility and adaptability
  - Magnetic integration
  - DSP and fiber-optic based control implementation
- IP status:
  - S. K. Mazumder, "Solid-state power-conversion system," US Patent # 11594978, February 28, 2023 (International patents are pending)
  - Open to T2M, licensing, and/or joint-venture possibilities



Future Work

- **List of future work:**
  - **Power scalability of the HFL-LPT for distribution-level (Tens of Megawatt level) implementation (near term)**
  - **Power scalability of the HFL-LPT for transmission-/sub-transmission-level (Hundreds of Megawatt level) implementation (mid to long term)**
  - **Support of U.S. DOE and Other Federal Agencies is expected to be crucial towards the initial development of these novel next-generation SST technologies that provide energy leadership, energy security, and sustainable-energy economy, and energy-based employment opportunities to the United States.**

THANK YOU

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Acronyms

Insert any acronyms used and the associated definition here.

- AC: Alternating Current
- BDV: Breakdown Voltage
- DOE: U.S. Department of Energy
- DSP: Digital Signal Processor
- EMI: Electromagnetic Interference
- FET: Field-Effect Transistor
- HFL: High Frequency Link
- KVA: Kilovolt Ampere
- LPT: Large Power Transformer
- RMS: Root Mean Square
- SiC: Silicon Carbide
- SST: Solid-State Transformer