PROJECT PROFILE
Topic: Power Electronics | Vertical: Safety & Reliability
Strategic Pathway: Grow
Project start and finish: FY25-FY27

POWER CONVERSION SYSTEM DESIGN AND MATERIALS – MODELING AND CONTROL

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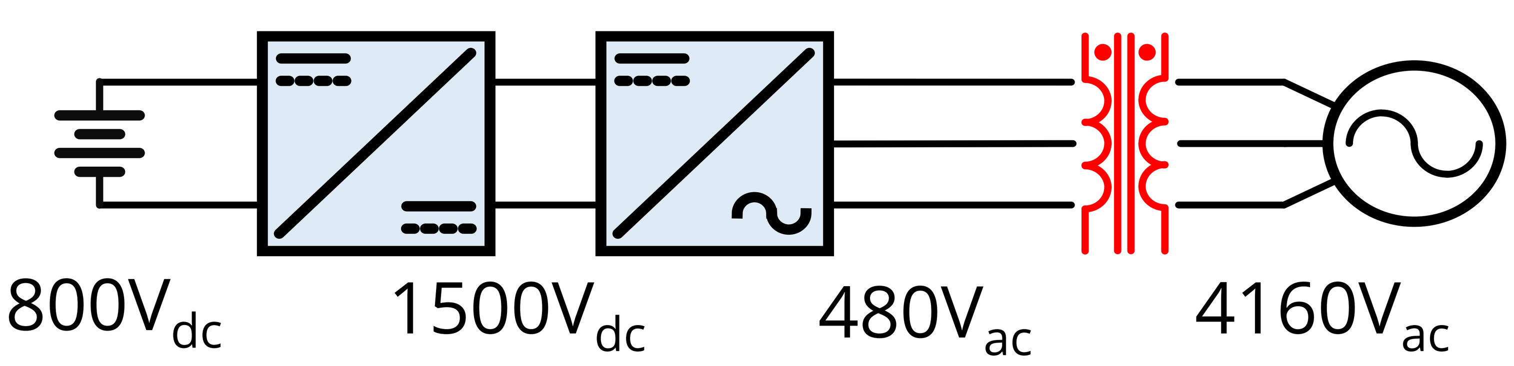
PROBLEM

- Utility-scale BESS power conversion system (PCS) rely on large line-frequency transformers (LFTs) for MV grid interconnection.



- LFT procurement lead times have increased to 24–30 months, creating a major deployment bottleneck for new BESS installations [1].
- Existing PCS architectures are difficult to scale, transport, and manufacture for rapidly growing grid and datacenter demand.

APPROACH

- Proposed PCS uses a modular MV multilevel inverter with cascaded isolated converters to interface batteries directly to MV grids with a LFT high-frequency transformers (HFT) .
- Architecture relies on low-cost commodity components with procurement lead times of weeks instead of years.
- The cascaded architecture introduces complex system- and module-level control interactions that can lead to overvoltage instability.
- This work develops coordinated inverter and dc/dc converter controls through integrated system simulation.
- High-frequency transformers offer smaller, lighter, lower-cost galvanic isolation, but high-voltage insulation and thermal demands challenge their implementation.
- This work developed a multi-material 3D-printed transformer package that integrates winding support, high-voltage insulation, and liquid-cooled thermal management into a compact structure.

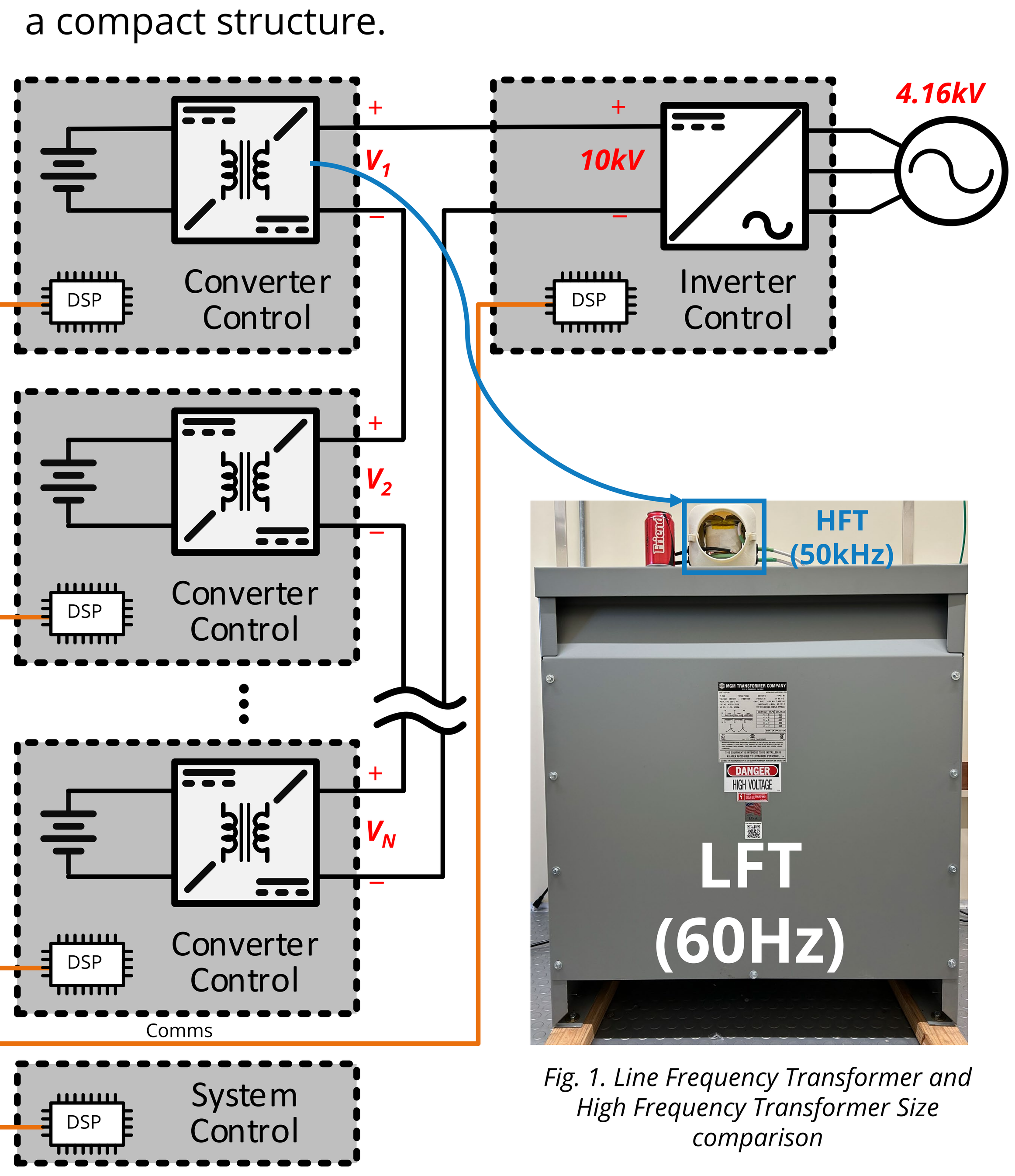


Fig. 1. Line Frequency Transformer and High Frequency Transformer Size comparison

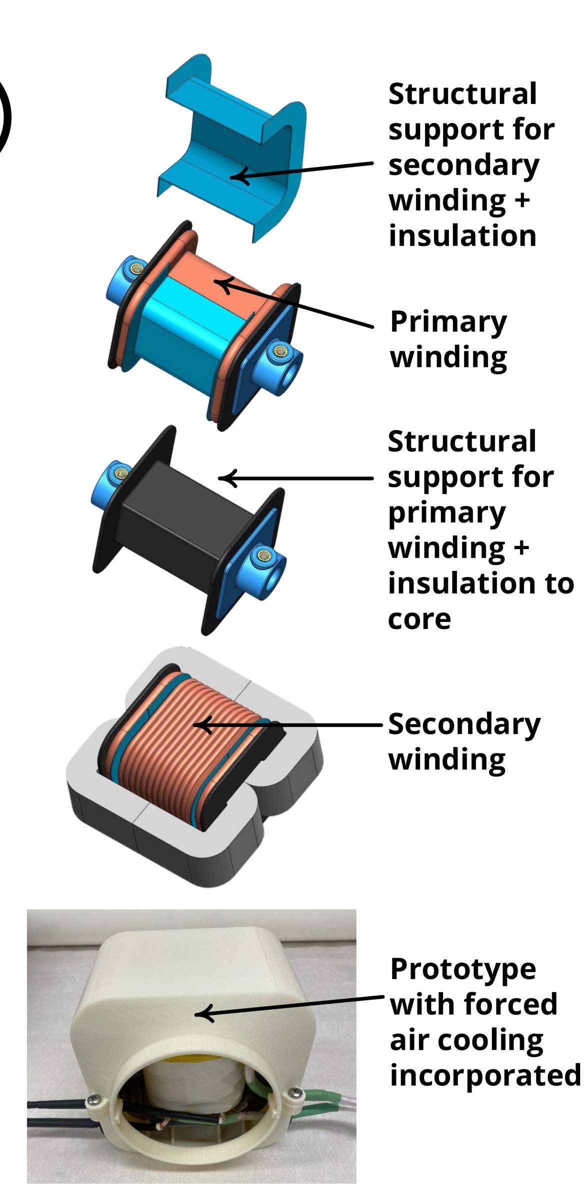


Fig. 2. Design of first HFT prototype

RESULTS

- The results show the response our developed control for 3-operating transitions: (1) no load to charging, (2) charging to discharging, and (3) loss of converter.
- A HFT prototype using natural convection and forced air cooling was tested at rated conditions to served as a baseline for comparison to the liquid-cooled prototype under construction.

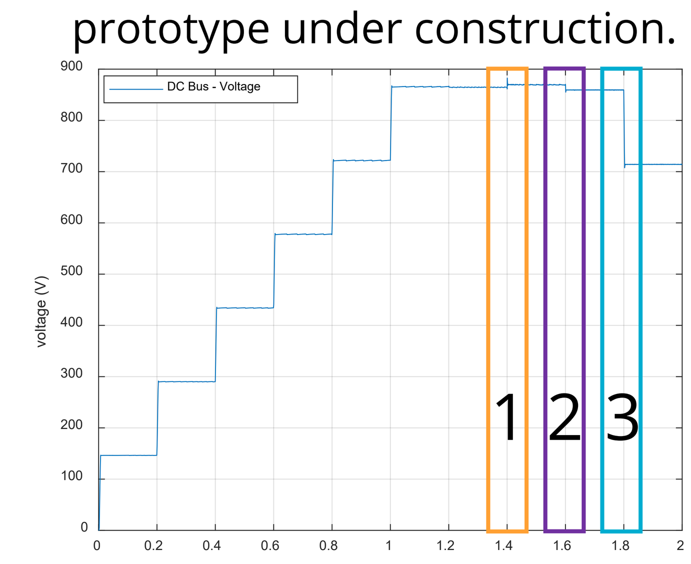


Fig. 3. DC Bus Voltage

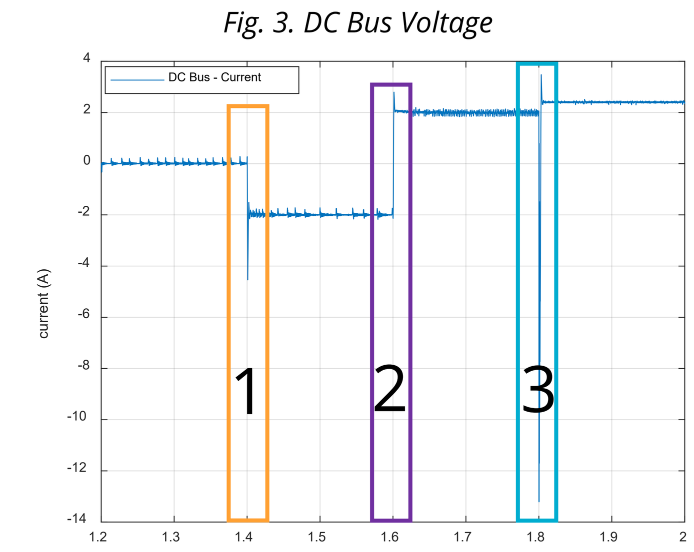


Fig. 4. DC Current Into Inverter

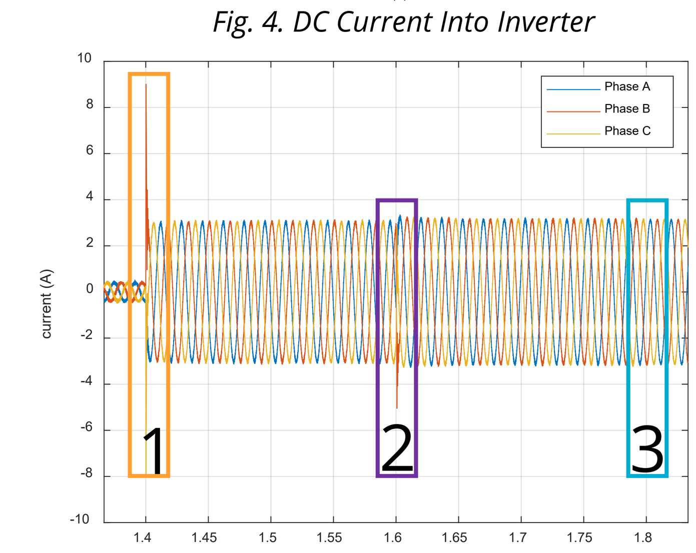


Fig. 5. AC Grid Current

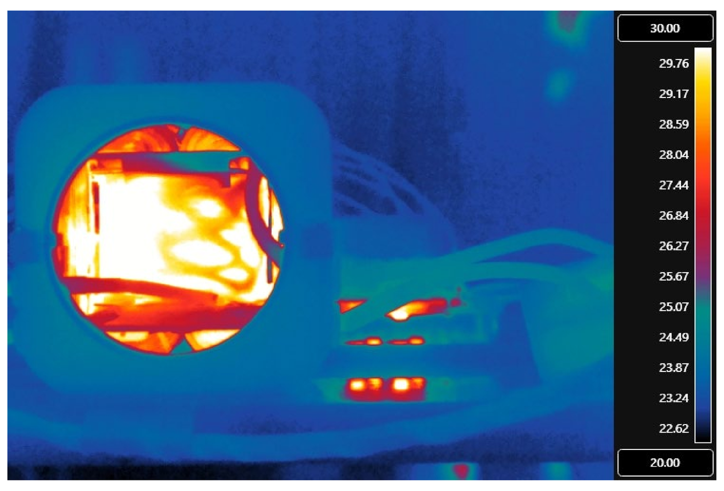


Fig. 6. Thermal Image of first HFT prototype

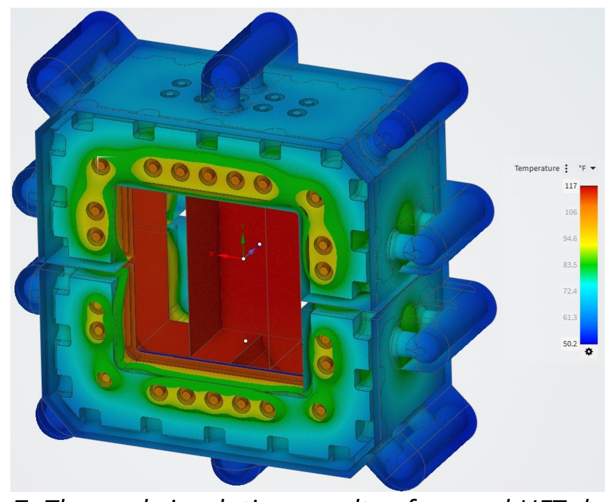


Fig. 7. Thermal simulation results of second HFT design

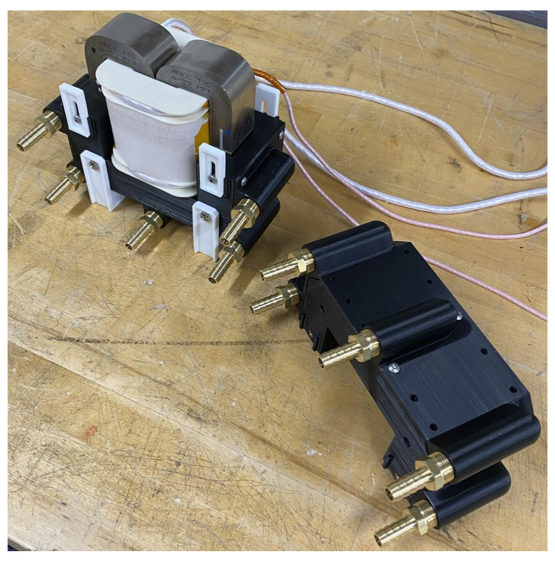


Fig. 8. Built design of second HFT

CONCLUSIONS & IMPACT

- Coordinated system- and module-level controls successfully maintained stable operation during bidirectional power flow.
- Developed an HFT design process that improves HV insulation reliability by eliminating liquid-initiated PD and chemical interactions with core ribbon coatings.
- Results show that transformerless modular MV PCS can enable scalable, manufacturable utility-scale BESS while reducing bottlenecks from transformer cost, size, and long lead times.

FUTURE DIRECTIONS

- A multilevel inverter will be built to complete the assembly of our LV PCS prototype to assess the veracity of our PCS control strategy in a safe hardware environment which will be directly applicable to the MV PCS design.

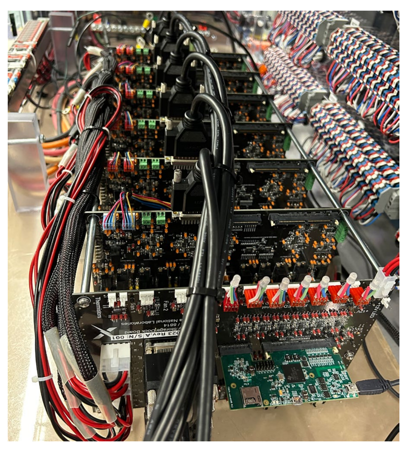


Fig. 9. LV Prototype Cascaded System

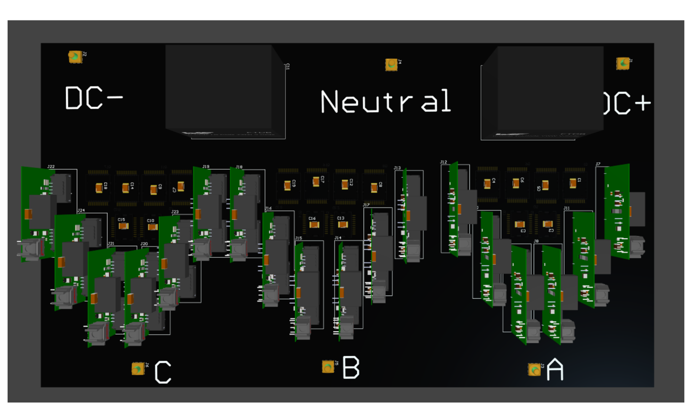


Fig. 10. LV Hardware Design of 3-Level ANPC

apex MEDIUM VOLTAGE

Fig. 11. Sandia's MV APEX Lab

This material is based upon work supported by the U.S. Department of Energy, Office of Electricity (OE), Energy Storage Division.

References

[1] U.S. Department of Energy, "The Supply Chain Crisis Facing the Nation's Electric Grid," 2022. https://www.energy.gov/policy/articles/supply-chain-crisis-facing-nations-electric-grid.