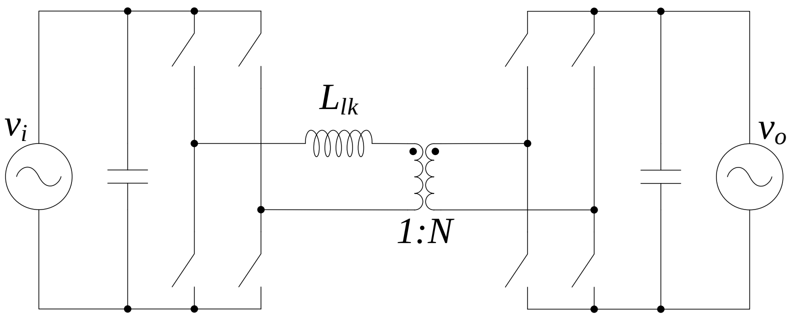
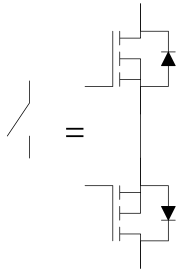
AC-AC Dual Active Bridge Converter Development

Jonathan Kimball, Missouri University of Science and Technology, kimballjw@mst.edu

Jacob Mueller, Sandia National Laboratories, jmuelle@sandia.gov

Project initiated May 2021





- This project addresses initial design and modeling of converter for prototype evaluation
  - Deliverables: PCB, transformer design; simulations
- AC-AC Dual Active Bridge topology has excellent potential for reducing size and complexity of solid-state transformers (SSTs)
- SSTs provide an ideal point of entry for utility operated energy storage resources
- High-frequency transformer is directly connected to ac ports through active bridges; no ac-dc or dc-ac conversion needed for main power flow
- Building block: scalable for power and voltage
- Challenges:
  - Pulsating power due to single-phase ac ports
  - Modeling—nonlinear, multiple frequencies
  - Control—regulating both active and reactive power flow
  - Synchronization—two ac ports

MISSOURI S&T

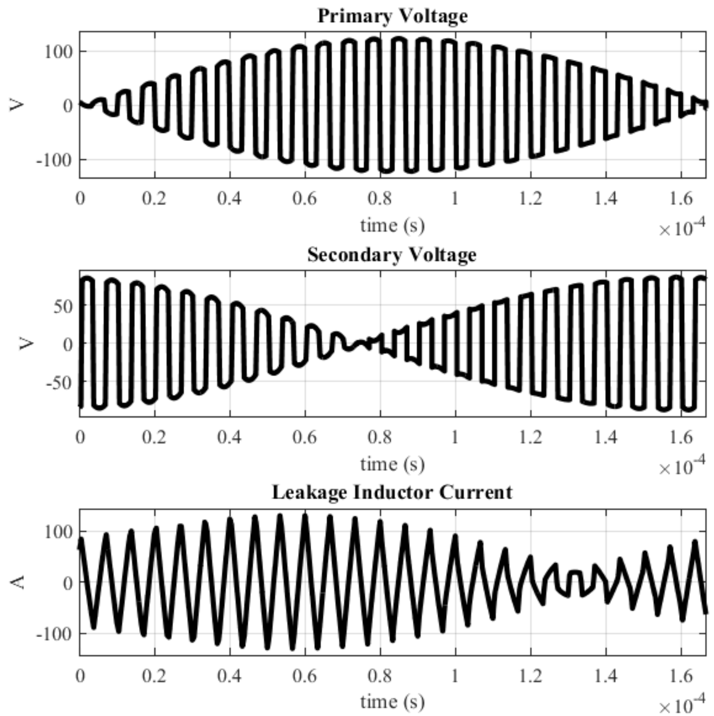
Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. SAND No. SAND2021-12871 C.

Basic Operational Concept

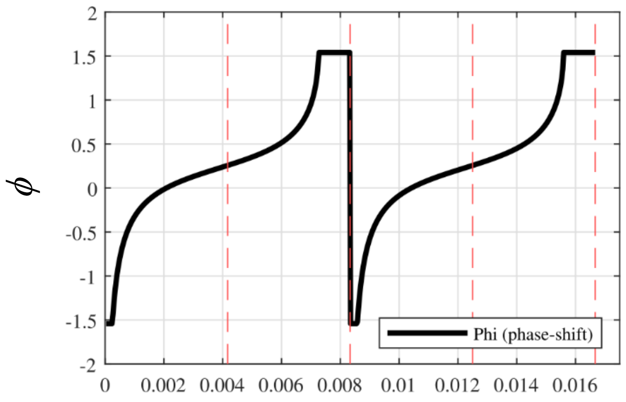
- H-bridges chop each ac waveform into a square wave with sine envelope
- Phase shift between primary and secondary controls power flow

$$p_o(t) = \frac{v_i v_o}{2\pi f_{sw} N L_{lk}} \left(|\phi| - \frac{\phi^2}{\pi} \right) \mathrm{sgn}(\phi)$$

- LC filters remove switching frequency content
    - Bidirectional power flow supported



Constant ϕ for active power only
Sinusoidal envelope on square-wave voltage

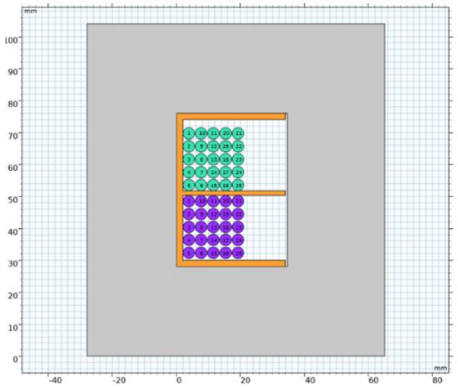


ϕ variation for non-unity power factor

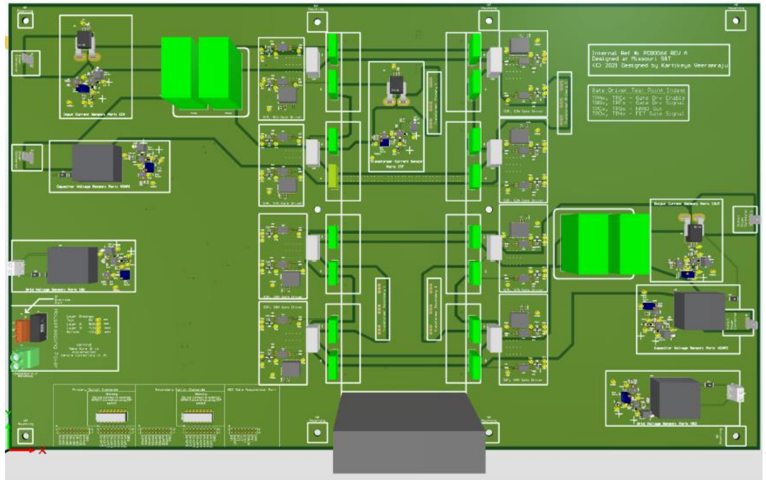
MISSOURI S&T

Project Short-Term Objectives

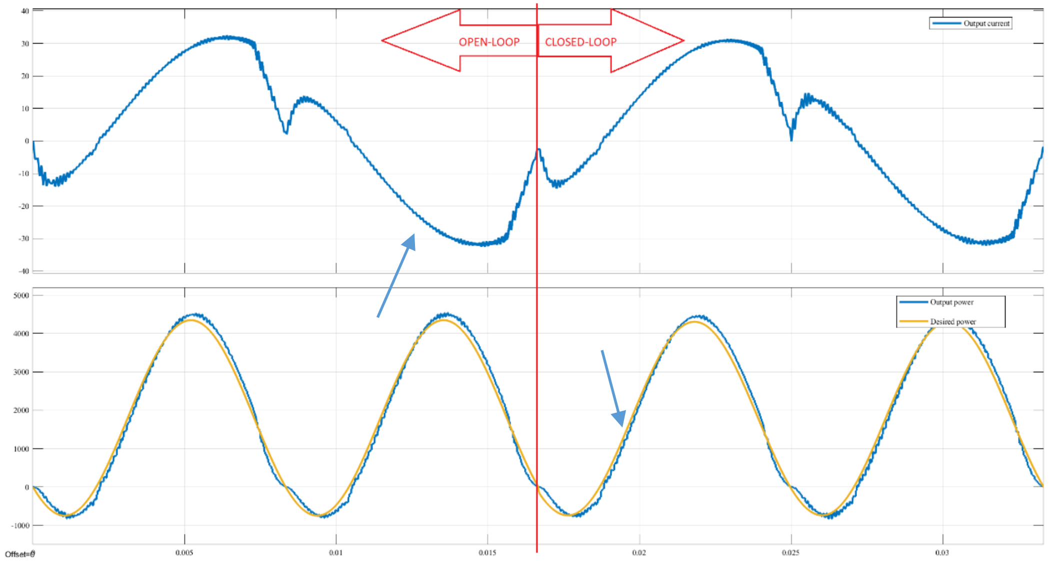
- Design ac-ac DAB suitable for 120 V, 3.6 kVA
  - PCB schematic and layout
  - Transformer design
- Simulations to explore converter characteristics
  - Startup, transient, steady-state
  - Simple closed-loop
  - Varying power factor: voltage zero-crossing leads to output distortion
  - Commutation sequence to ensure zero-voltage switching



Custom Transformer Design



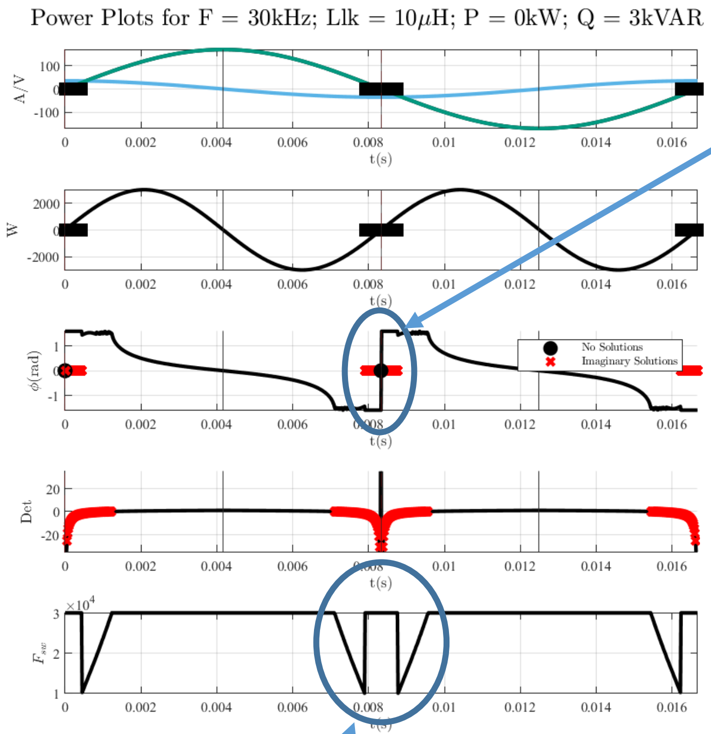
PCB Layout



Simulated current and power waveforms

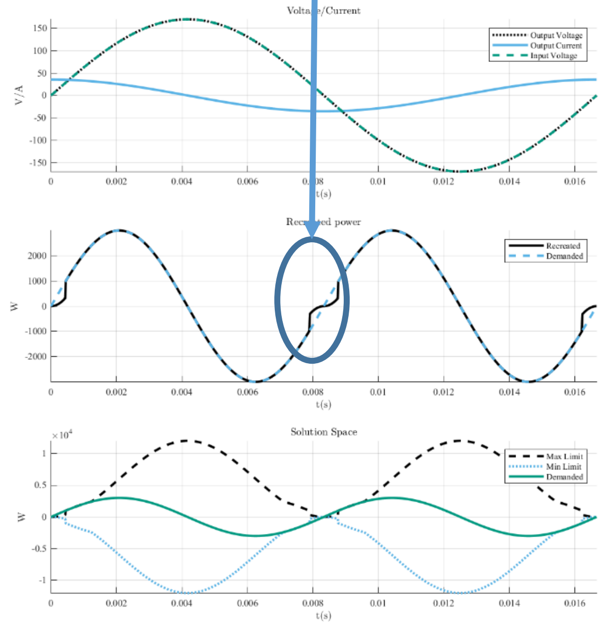
Major Findings

- Relationship between phase shift and active/reactive power flow established
- Phase saturation, frequency dropping can mitigate zero-crossing distortion
- First steps towards generalized average model taken – multi-frequency averaging
  - Must include both line frequency and switching frequency **dynamic** behavior



Near zero voltage, no power transfer possible

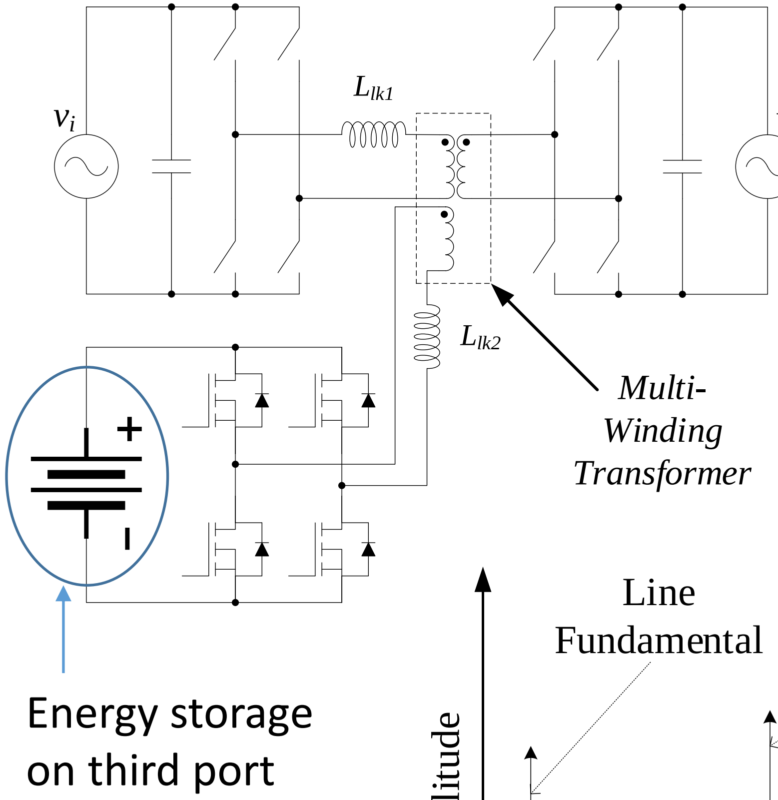
Variable frequency expands available operating range

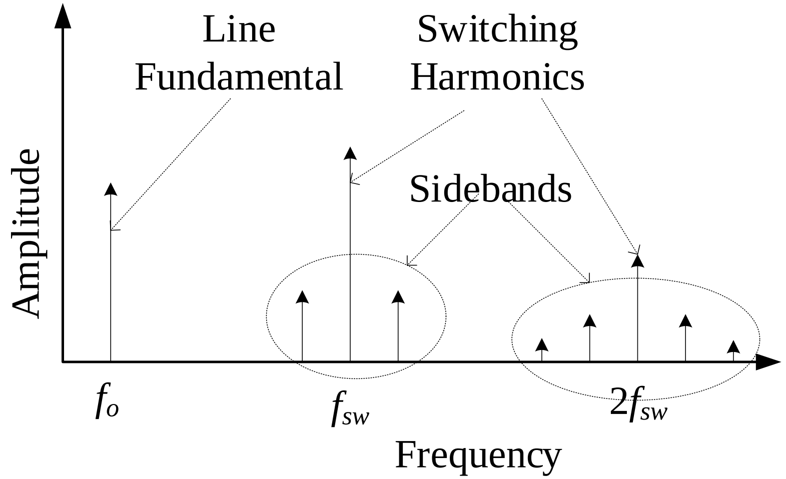


MISSOURI S&T

Next Steps

- PCB designed; converter will be built and tested at Sandia
  - Firmware needed
- Generalized average model not yet complete; requires 2D convolution to capture <u>dynamics</u>, not just static response
- Add a third port: dc port with energy storage to eliminate zero-crossing distortion, enable power flow between asynchronous grids





MISSOURI S&T

We gratefully acknowledge the DOE OE Energy Storage Program and Dr. Imre Gyuk for generous financial support of this project.