This paper describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government.
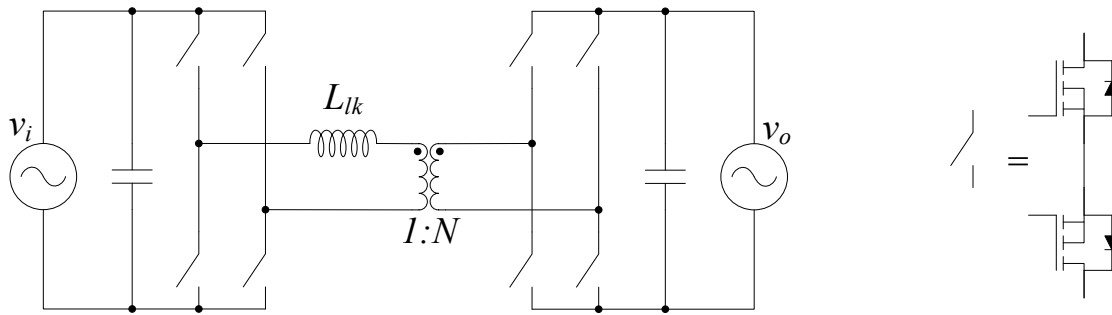
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# AC-AC Dual Active Bridge Converter Development

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- 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
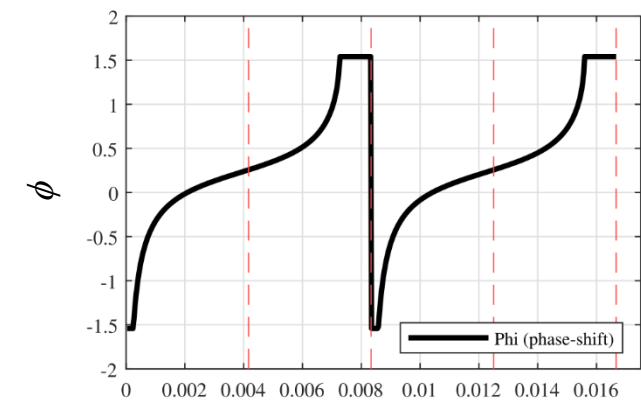
# Basic Operational Concept

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

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

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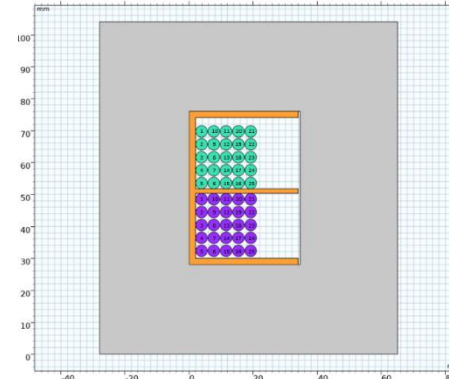  - Bidirectional power flow supported



Constant $\phi$ for active power only
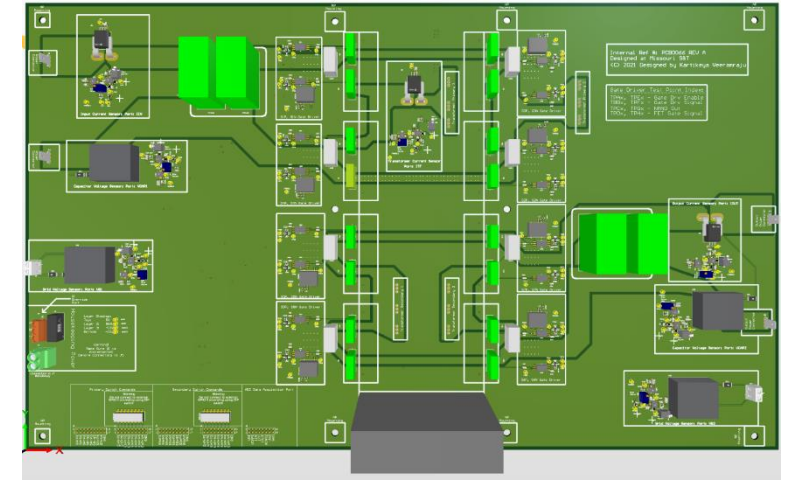Sinusoidal envelope on square-wave voltage



$\phi$ variation for non-unity power factor
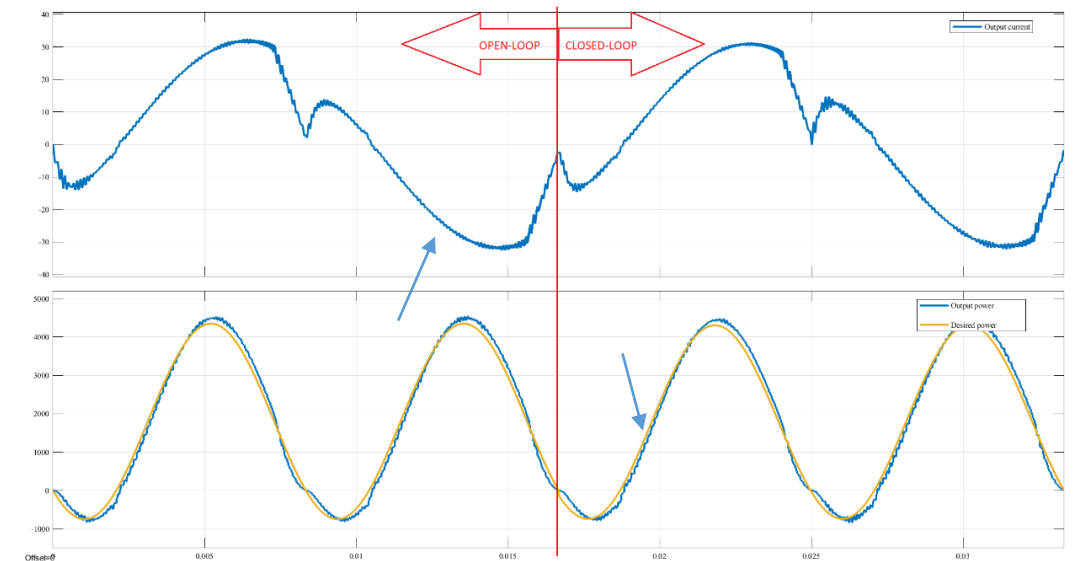
# Project Short-Term Objectives

- 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
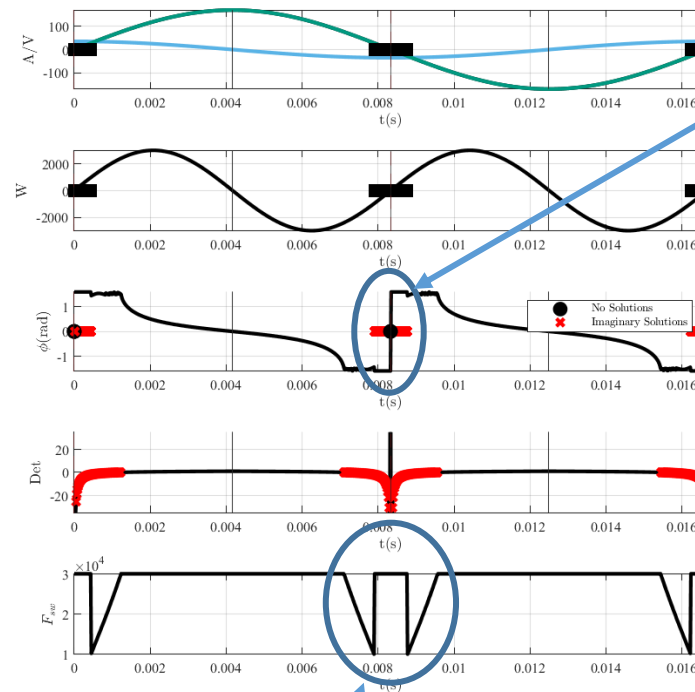


PCB Layout



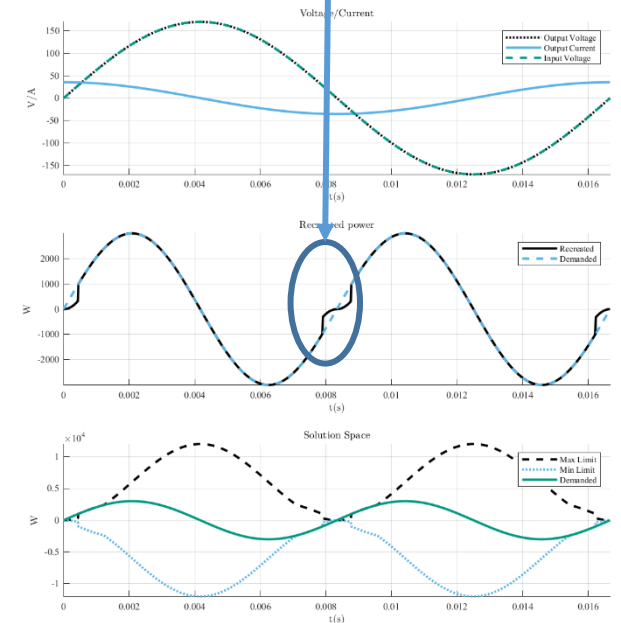Simulated current and power waveforms

# 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



Power Plots for F = 30kHz; Llk = $10\mu$H; P = 0kW; Q = 3kVAR

Near zero voltage, no power transfer possible

Variable frequency expands available operating range

# 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

Energy storage on third port

$L_{lk1}$

$v_i$

$v_o$

$L_{lk2}$

*Multi-Winding Transformer*

Line Fundamental

Switching Harmonics

Sidebands

Amplitude

$f_o$     $f_{sw}$     $2f_{sw}$

Frequency

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