EE 5743

Advanced Power Electronics Lab

Developed through ONR Funding

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College of Science & Engineering
University of Minnesota

EE 5743 Advanced Power Electronics

Advanced lab course for EE majors specializing in power electronics:

- multi-level drive topologies
- multi-phase drive topologies
- pulse-width modulation techniques
- active rectification
- bidirectional converters
- soft switching

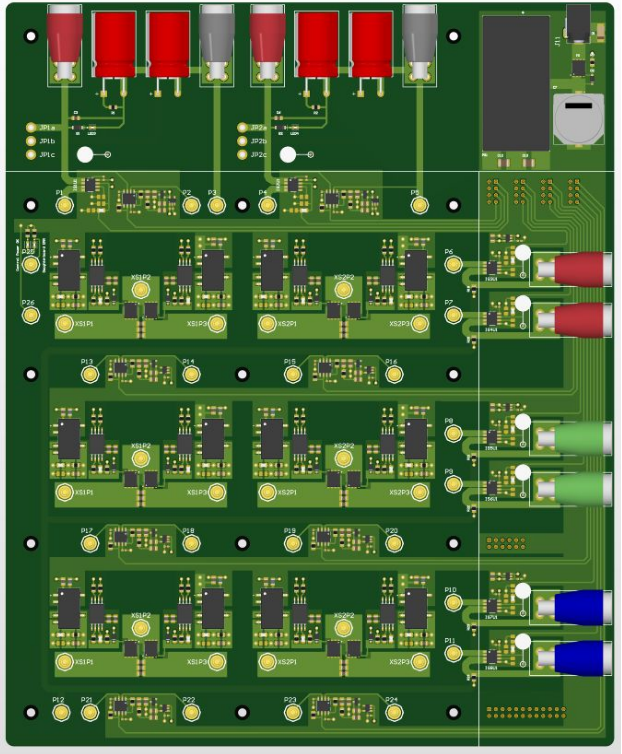
Note: this lab is under development.

EE 5743 Course Content

Lab Content:

- Half-Bridge Inverter
- H-Bridge Inverter
- Cascaded H-Bridge Inverter
- 3-Phase Inverter
- Diode-Clamped (NPC) Inverter
- Flying Capacitor Inverter
- Modular Multilevel Converter (MMC)
- Active Rectifier
- Phase-Shifted Full-Bridge Converter
- Soft Switching
- Dual Active Bridge Converter

Modular Daughterboard Approach



12-Switch Power Electronics Breadboard (PEB)

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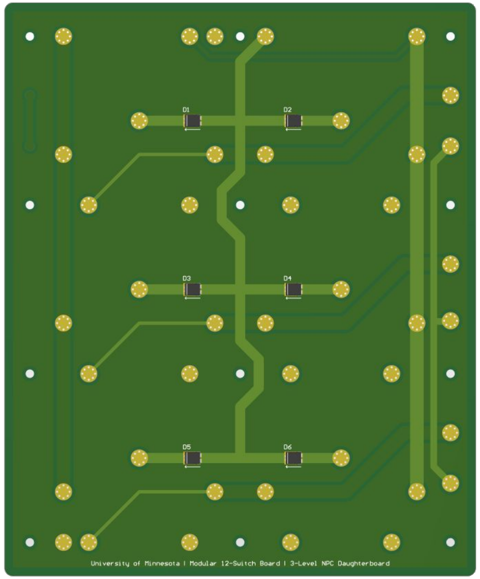

3-Level NPC Daughterboard

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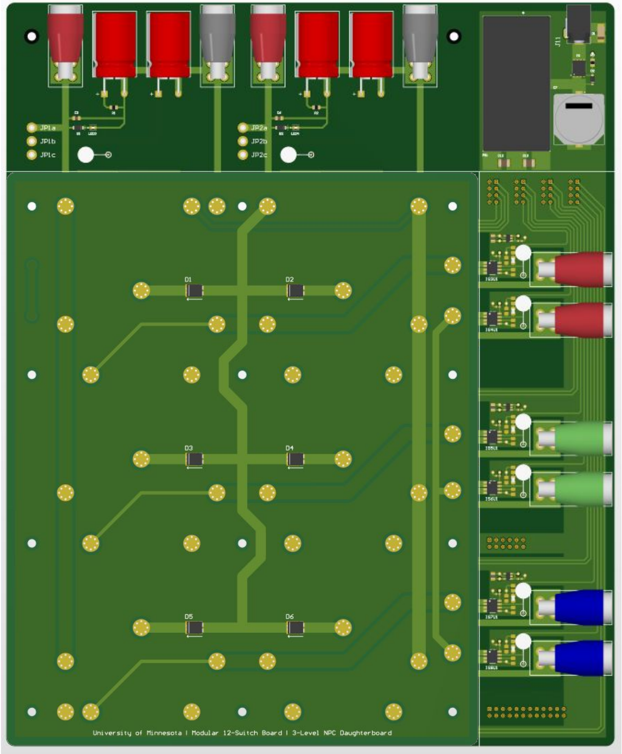
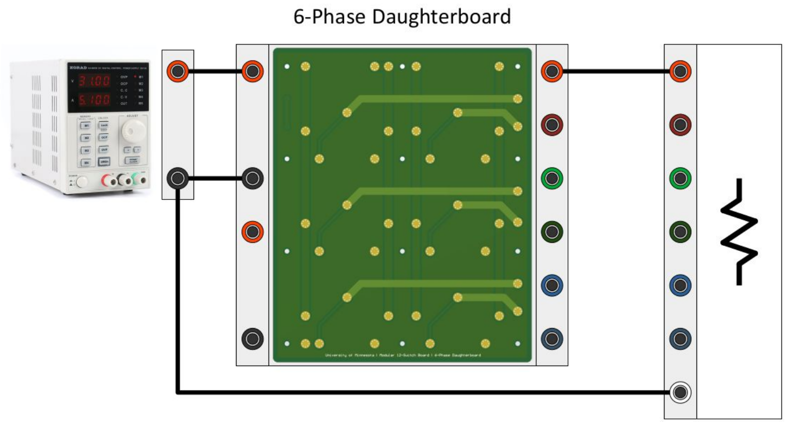


3-Level NPC Inverter

Lab 1: Half-Bridge Inverter

Learning Objectives

- Control of a Half-Bridge Inverter
- Carrier-based PWM



Summary

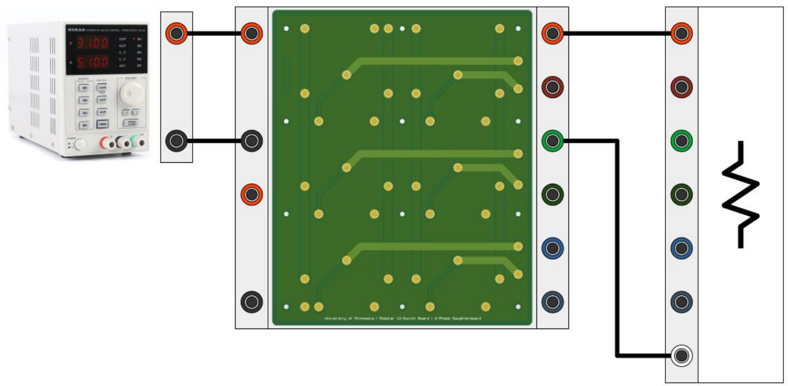
- This lab introduces the basics of using the hardware and software.
- It demonstrates generating a 2-level output voltage waveform using a half-bridge inverter.

Lab 2: H-Bridge Inverter

Learning Objectives

- Control of an H-Bridge Inverter

6-Phase Daughterboard



Summary

- This experiment demonstrates how using a pair of back-to-back half-bridges allows an output voltage waveform with 3 distinct voltage values to be achieved.

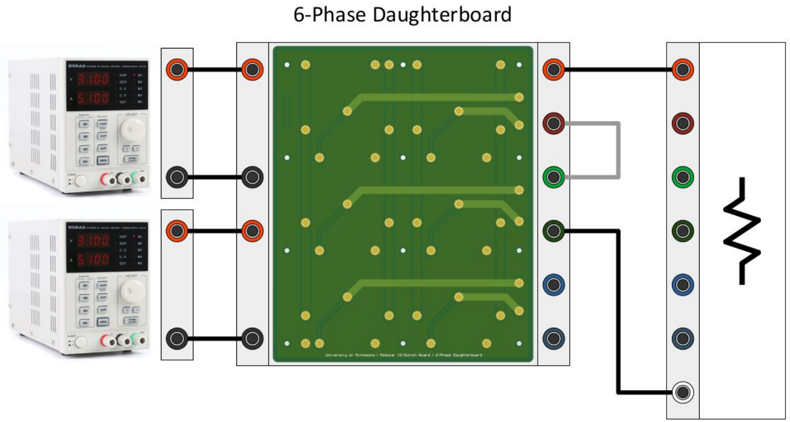
Lab 3: Cascaded H-Bridge Inverter

Learning Objectives

- Control of a 5-level Cascaded H-Bridge Inverter

Summary

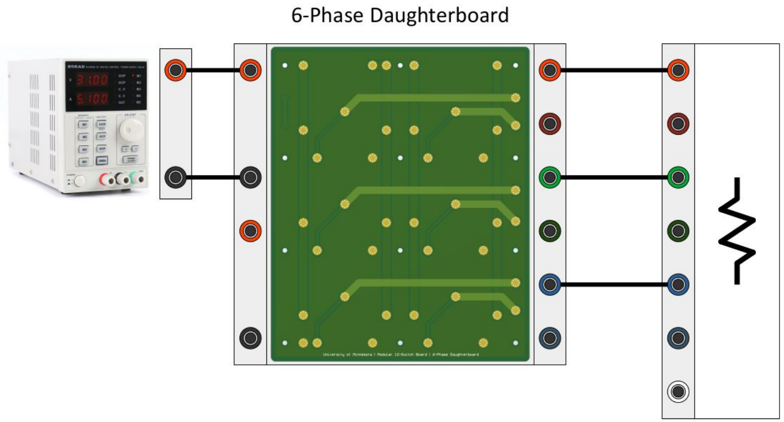
- Demonstrates how further increases in the number of distinct output voltage levels can be achieved by stacking h-bridge inverters.



Lab 4: 3-Phase Inverter

Learning Objectives

- Control of a 3-Phase Inverter



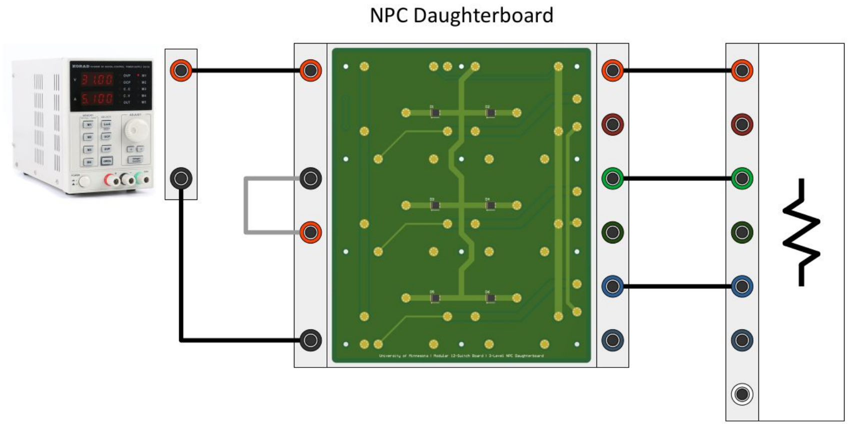
Summary

- Demonstrates how a three-phase connection allows output voltage waveform generation with 3 distinct output voltage levels for each phase while only adding two switches compared to a single-phase h-bridge inverter.

Lab 5: Diode-Clamped (NPC) Inverter

Learning Objectives

- Control of a NPC Inverter
- Phase-Shifted Carrier PWM
- Level-Shifted Carrier PWM
- Capacitor Voltage Balancing



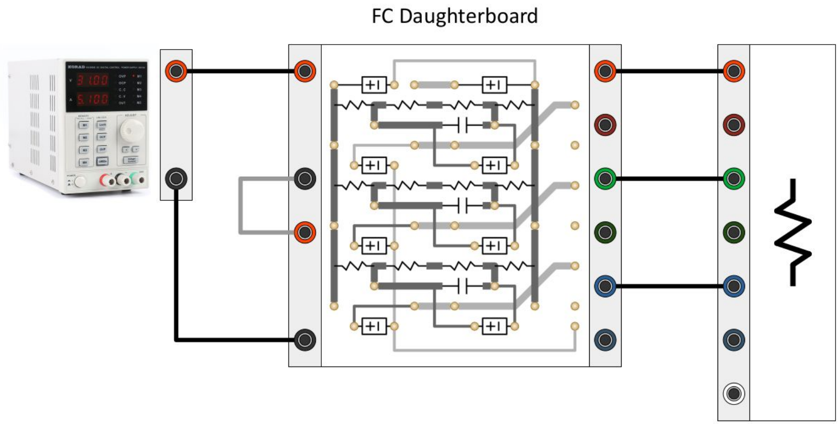
Summary

- This lab demonstrates the most common multilevel converter topology.
- Introduces multi-carrier pulse-width modulation.
  - phase-shifted carriers
  - level-shifted carriers
- Introduces the concept of needing to balance voltage across a stack of capacitors using redundant switching states.

Lab 6: Flying Capacitor Inverter

Learning Objectives

- Control of a Flying Capacitor Inverter
- Phase-Shifted Carrier PWM
- Level-Shifted Carrier PWM
- Capacitor Voltage Balancing



Summary

- Demonstrates a second multilevel inverter topology.
- Further demonstrates the need to use redundant switching states to control the voltage for the flying capacitors.

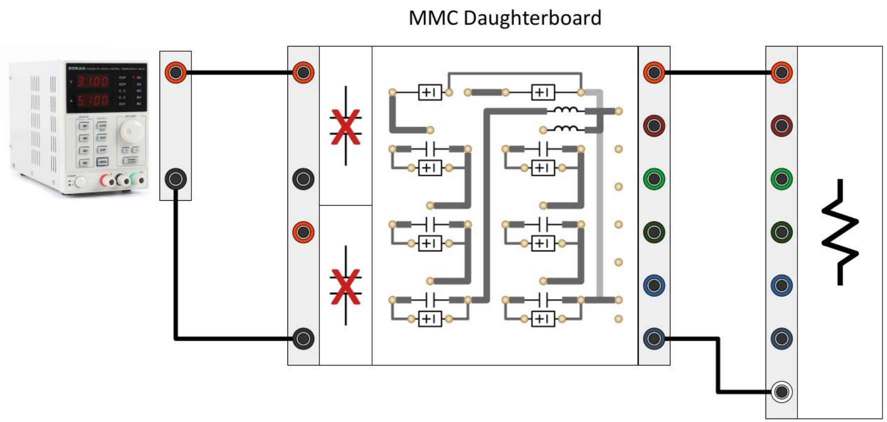
Lab 7: Modular Multilevel Converter (MMC)

Learning Objectives

- Control of a 5-level single-phase Modular Multilevel Converter

Summary

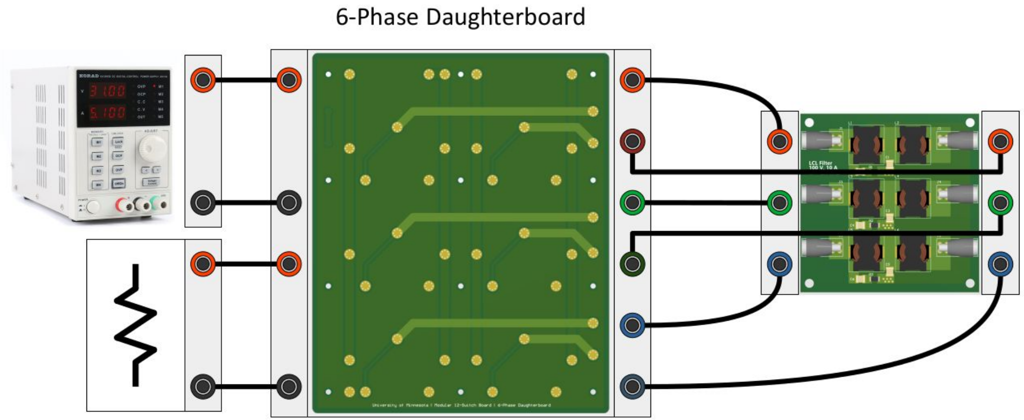
- Demonstrates a single-phase four-level inverter topology where the DC link capacitance is distributed across a stack of 6 half-bridge submodules.



Lab 8: Active Rectifier

Learning Objectives

- Passive Rectification
- Phase-Locked Loops
- Power Factor Control using Active Rectifier



Summary

- This experiment introduces students to active rectification to achieve unity power factor.
- Both passive and active rectification are demonstrated, using the body diodes of the switches for the demonstration of passive rectification.

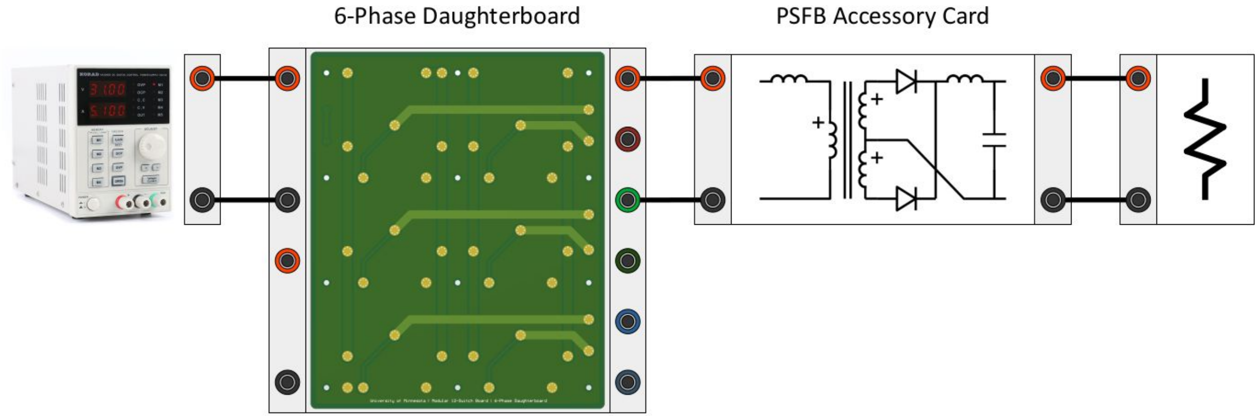
Lab 9: Phase-Shifted Full-Bridge Converter

Summary

- Control of a Phase-Shifted Full-Bridge Converter

Summary

- Demonstrates a transformer -isolated unidirectional DC-DC converter using an h-bridge and diode rectifier.



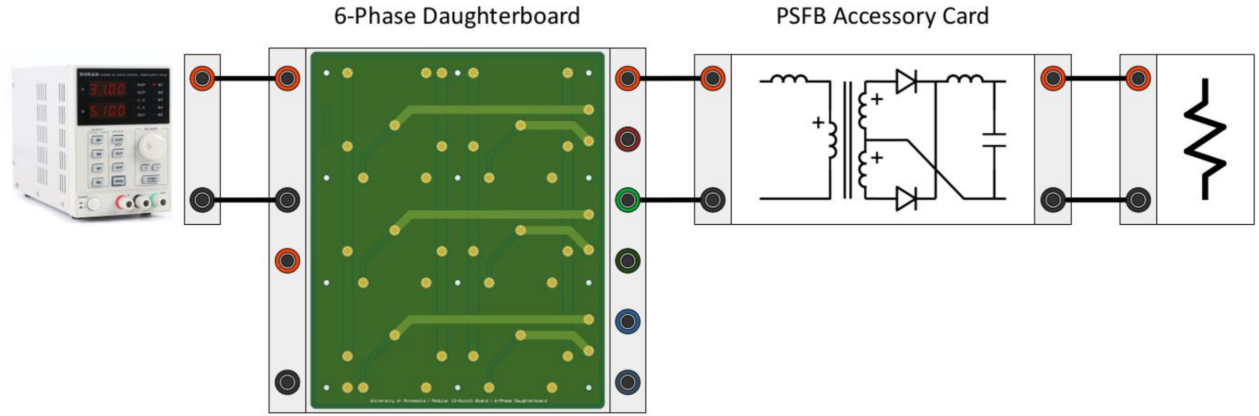
Lab 10: Soft Switching

Learning Objectives

- Resonant Operation
- Zero-Voltage Switching

Summary

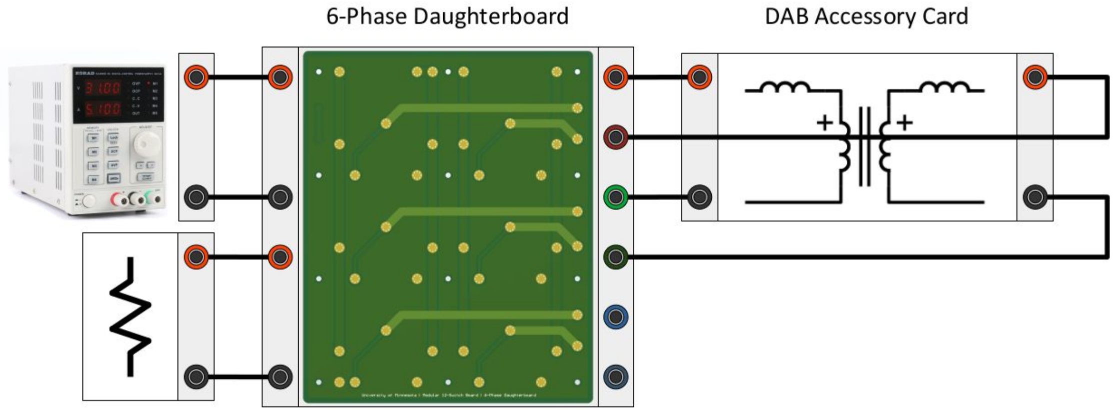
- Demonstrates resonant operation of the phase-shifted full-bridge converter to achieve zero-voltage switching (ZVS).



Lab 11: Dual Active Bridge Converter

Learning Objectives

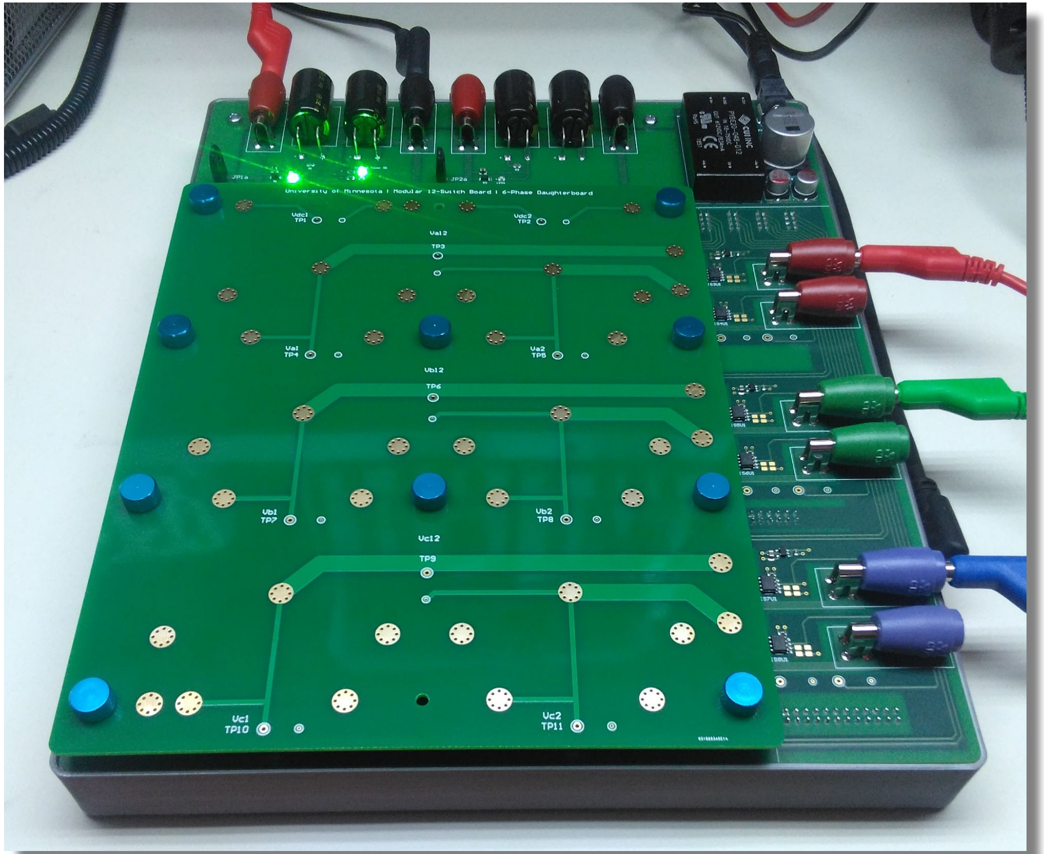
- Bidirectional Converters
- Control of a Dual Active Bridge Converter



Summary

- Demonstrates transformer -isolated bidirectional DC-DC converter using back-to-back h-bridge converters.
- **Note:** because the power supply cannot sink power, this demonstration is limited to unidirectional power flow.

Modularity and Extensibility



- Controller interfaces with Sciamble Workbench
- Beyond lab exercises, platform could be used for student projects, research
- Custom daughterboards can be used to implement novel converter topologies
- Multiple PEBs can be combined to implement more complex drives
- Multiple setups can be combined to implement larger systems (microgrids)

EE 5743 Availability

This lab course is **under development**.

This course will first be offered at UMN at a date to be determined.

External availability of the course materials is expected **Fall 2024**.

Acknowledgements

- We would like to thank the Office of Naval Research (ONR) for their support for this work through the following grant:
    - N00014-19-1-2018 “Developing WBG-Based, Extremely Low-Cost Laboratories for Power Electronics, Motor Drives, and Power System Protection and Relays for National Dissemination”