EE 2703

Sustainable Electricity Supply: Renewables and Conservation Lab

David Maiden Mueller
PhD Researcher
maide002@umn.edu

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College of Science & Engineering
University of Minnesota

EE 2701 / 2703 Sustainable Electricity Supply

EE-2701 is an introductory course for EE majors and non-majors, providing an overview of:

- electrical generation
- energy storage
- electrical distribution
- electrical applications

The accompanying lab (EE-2703) provides hands-on experience with the fundamentals of AC electricity, exploring frequency-dependent impedance of inductors and capacitors, transformers, converting from AC to DC, converting from DC to AC, and AC motors and generators.

Note: this lab is under development.

EE-2701 / 2703 Course Content

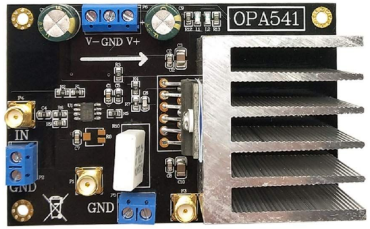
Course Content:

- Climate Change: Causes and Consequences
- Electricity as a Solution to Combat Climate Change
- Energy from Conventional Fossil Fuel Sources
- Hydroelectric Power
- Nuclear Power
- Wind Power
- Solar Power
- AC Circuit Fundamentals
- Transformers and Transmission Lines
- Buck and Boost Converters
- Motors and Generators
- Electrifying Transportation
- Energy Storage
- Energy Conservation

Lab Content:

- Introduction to AC Power
- 3-Phase AC Systems
- AC Impedance of a Capacitor
- AC Impedance of an Inductor
- Resonance and Filters
- Transformers
- Diode Rectifiers
- Mosfet Switches
- Half-Bridge Inverter
- Motors and Generators
- Grid Energy Storage
- Grid Power Flow

Lab 1: Introduction to AC Power



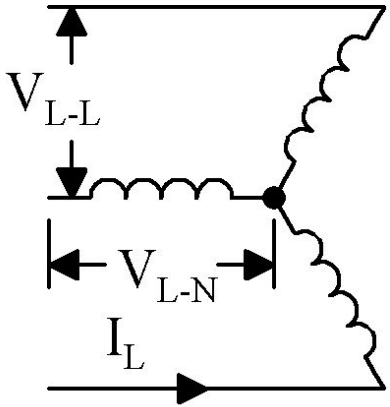
Summary

- In this experiment, the students will learn how to use a function generator to generate AC waveforms and an oscilloscope to measure them.
- They will measure voltage and current waveforms for three different loads (resistive, capacitive, inductive) to explore phase angle relationships between waveforms.

Learning Objectives

- Using a Function Generator, Power Amplifier, Oscilloscope
- Frequency, Amplitude, Phase Angle
- Instantaneous and Time-Averaged Power
- Root-Mean-Square Measurements

Lab 2: 3-Phase AC Systems



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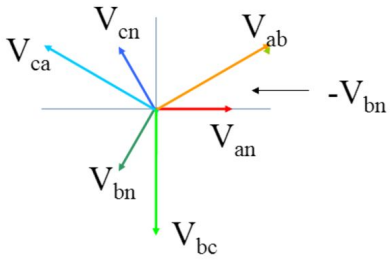


[2]

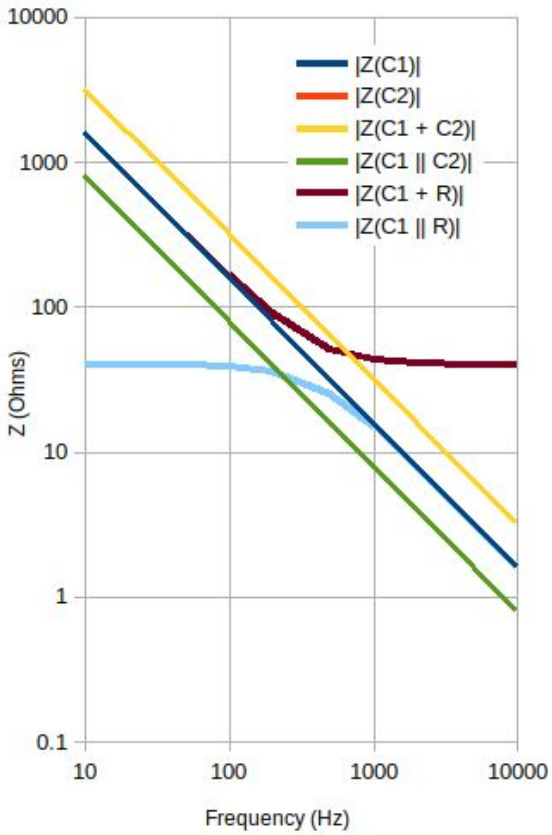
Summary

- In this experiment, students will explore three-phase (wye connected) circuits and calculations involving three-phase power through simulation.

Learning Objectives

- Line-to-Line Voltage
- Line-to-Neutral Voltage
- 3-Phase Power
- 2-Wattmeter Measurement

Lab 3: AC Impedance of a Capacitor



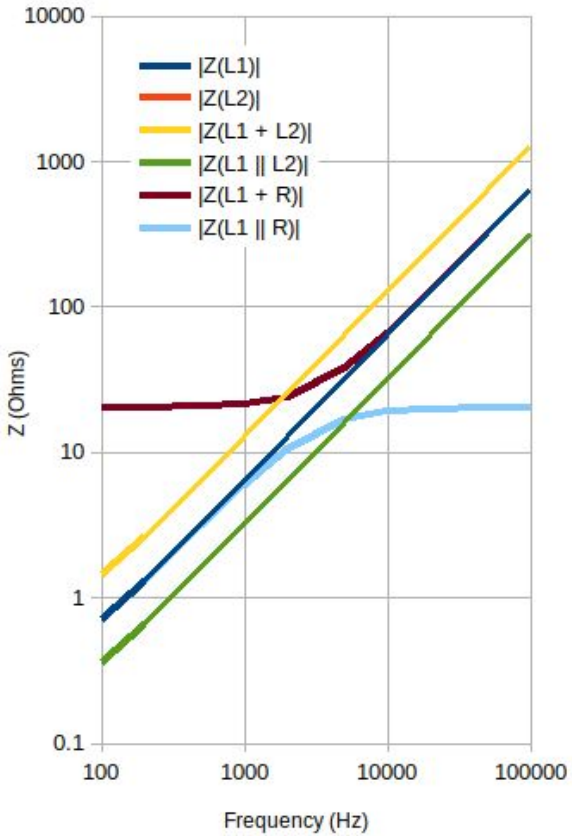
Summary

- In this experiment, students explore the impedance of series and parallel combinations of capacitors and resistors as a function of frequency.

Learning Objectives

- Impedance of a Capacitor
- Real vs Reactive Power
- Power Factor
- RC Series and Parallel Combinations

Lab 4: AC Impedance of an Inductor



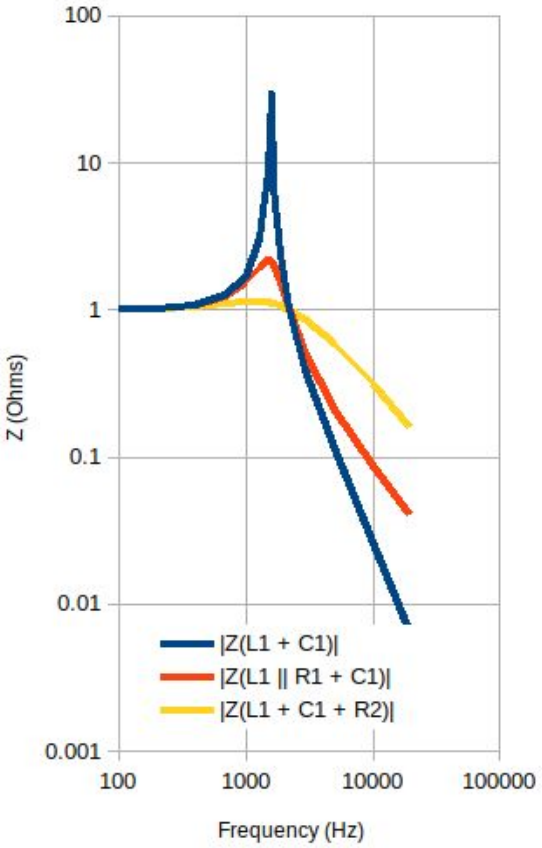
Summary

- In this experiment, students explore the impedance of series and parallel combinations of inductors and resistors as a function of frequency.
- Square-wave excitation will be used to demonstrate saturation.

Learning Objectives

- Impedance of an Inductor
- Magnetic Saturation
- Real vs Reactive Power
- Power Factor
- RL Series and Parallel Combinations

Lab 5: Resonance and Filters



Summary

- In this experiment, students will explore the impedance of series and parallel combinations of inductors and capacitors as a function of frequency.
- Resonance and methods to damp resonance will be demonstrated.

Learning Objectives

- AC Impedances in Series and Parallel
- Resonance

Lab 6: Transformers

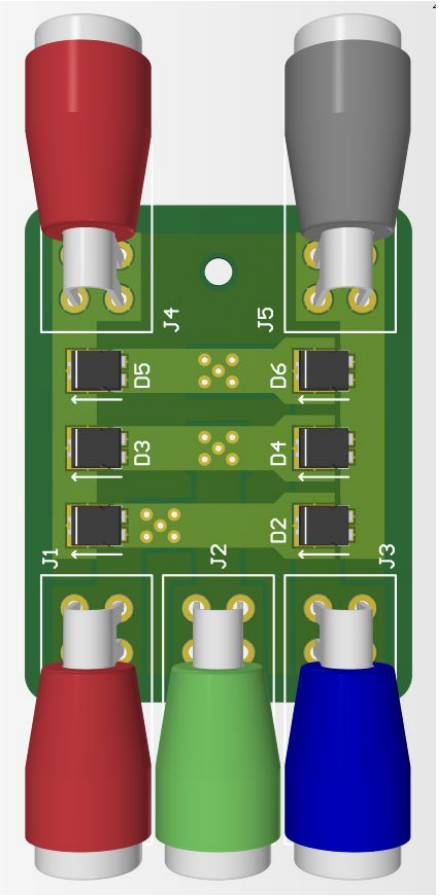
Summary

- In this experiment, students will explore using transformers to step-up or step-down AC voltages.
- Equivalent resistance (with an intermediate transformer) will also be considered.
- The transformers will be assembled by the students from a kit as a part of the exercise.

Learning Objectives

- Isolation Transformer
- Step-Up Transformer, Step-Down Transformer
- Equivalent resistance across a transformer

Lab 7: Diode Rectifiers



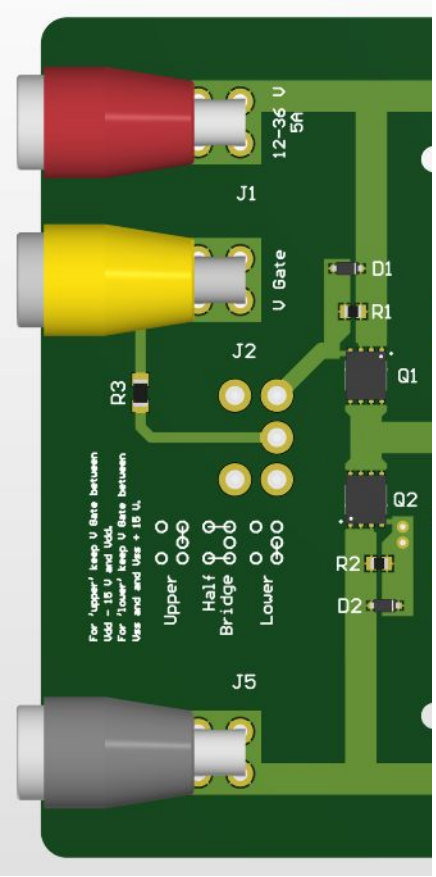
Summary

- In this experiment, students will explore diodes and using them to convert from AC to DC.
- First, the students will map out the iV curve for a diode using a power supply in constant-current mode.
- Next, the students will compare the output voltage waveforms for half-wave and full-bridge rectifiers, with and without output filter capacitors.

Learning Objectives

- iV Curve for a Diode
- Half-Wave Rectifier
- Full-Bridge Rectifier

Lab 8: Mosfet Switches



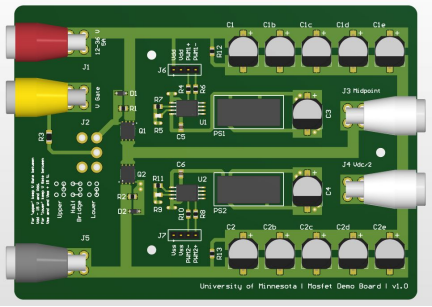
Summary

- In this experiment, students will explore the use of mosfets both as switches and as voltage-controlled resistors.
- Gate voltage will be controlled using a second DC power supply.
- Both n-channel and p-channel mosfets will be considered.

Learning Objectives

- N-Channel Mosfets
- P-Channel Mosfets
- Mosfets as Switches
- Mosfets as Voltage-Controlled Resistors

Lab 9: Half-Bridge Inverter



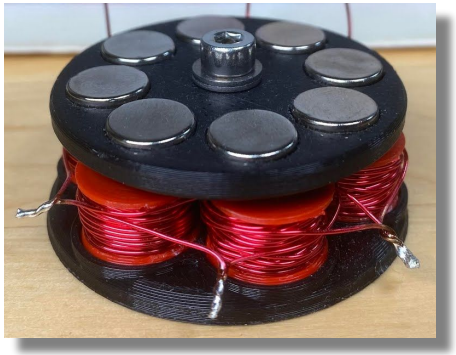
Summary

- In this experiment, students will explore converting from DC to AC using the pair of switches as a half-bridge inverter.
- A controller will be connected to the board used for the previous mosfet experiment.
- Pulse-width modulation using the combination of sine-wave and triangular carrier signals will be demonstrated.

Learning Objectives

- Pulse-Width Modulation
- Half-Bridge Inverter

Lab 10: Motors and Generators



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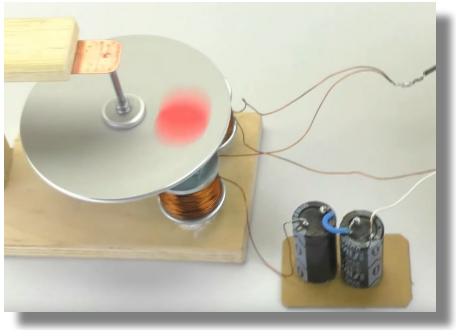

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Summary

- In this experiment, students will assemble kits that demonstrate:
  - generating AC power using a permanent magnet generator
  - converting AC power into motion using an induction motor

Learning Objectives

- Magnets
- Electromagnets
- Attraction / Repulsion between Unlike / Like Magnetic Poles
- Induced Voltage
- PMAC Generator
- Induction Motor (split capacitor)

1. https://www.youtube.com/watch?v=gBPZYLpVtj4
2. https://www.youtube.com/watch?v=ViapciJ7G3k

Lab 11: Grid Energy Storage


[1]


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Summary

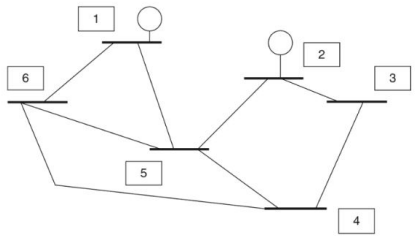
- In this experiment, students will explore the importance of grid energy storage by comparing cost and carbon emissions for a simulated power grid with and without storage.
- This experiment will involve a spreadsheet model where the students will schedule a series of generators (including solar, wind, and natural gas) to meet an example load curve.

Learning Objectives

- Balancing Generation and Load on the Power Grid
- Storage Efficiency
- Required Storage Depth

1. Photo by Christoffer Reimer. Licensed under Creative Commons Attribution 3.0 ↪
2. Photo by Tom Corser www.tomcorser.com. Licensed under Creative Commons Attribution - Share Alike 3.0 ↪
3. Photo by Kawasaki Internet Guide. Licensed under Creative Commons Attribution 3.0 ↪

Lab 12: Grid Power Flow



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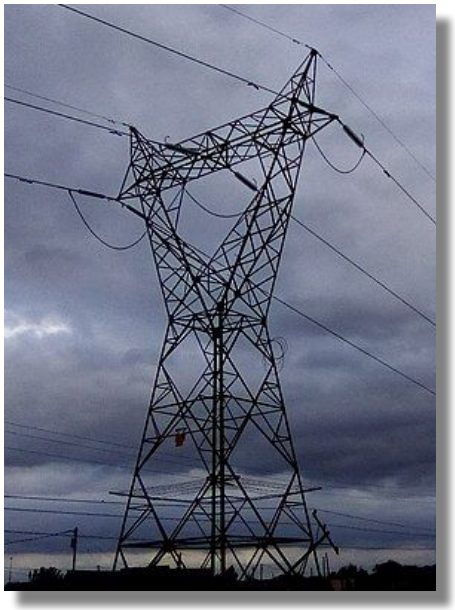


[2]

Summary

- In this experiment, students will explore transmission grids using a spreadsheet model of a 6-bus grid.
- Analysis will include changing loads and sources as well as removing lines and observing the effect on the power flow.

Learning Objectives

- Voltage Drop and Phase Shift between Busses
- Load Sharing between Parallel Lines
- Power Limits on Lines
- Effect of Faults on Power Flow

1. Wood, Wollenberg, and Sheblé. Power Generation, Operation, and Control. 3rd edition. Hoboken, New Jersey: Wiley, 2014.
2. Photo by Neotigen. Licensed under Creative Commons Attribution - Share Alike 4.0

EE-2701 / 2703 Availability

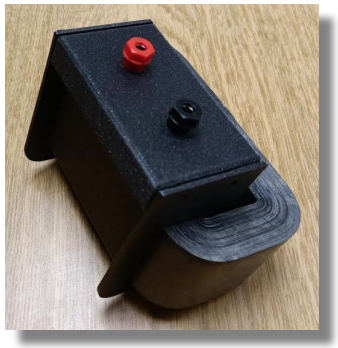
The lecture was last offered at UMN during the **Spring 2023** semester.

The lab course is **under development**.

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

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

Acknowledgements



- I would like to acknowledge Samantha Singh, one of our 2023 summer interns, for her work on the modular transformer kits. Samantha will be a Junior this fall at the Blake School.