EE 1703

Climate Crisis: Implementing Solutions Lab

Developed through ONR Funding

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COLLEGE OF Science & Engineering
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EE-1701 / 1703 Climate Crisis: Implementing Solutions

EE-1701 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-1703) provides hands-on experience with the fundamentals of DC electricity, exploring solar and wind generation, battery storage, and applications of electrical energy through LEDs and motors.

EE-1703 Course Content

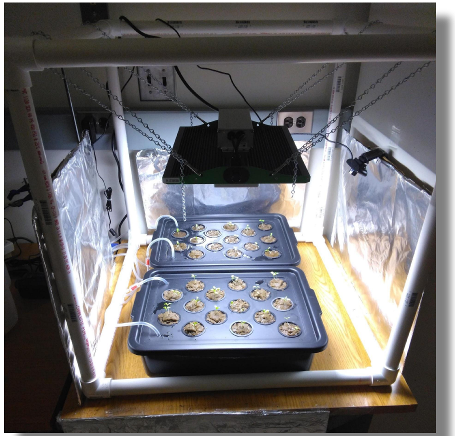
EE-1701 Course Content:

- Climate Change: Causes, Contributors, Consequences
- Electricity as a Solution to Combat Climate Change
- Energy from Conventional Fossil Fuel Sources
- Nuclear Power
- Hydroelectric Power
- Wind Power
- Solar Power
- Residential/Rooftop Solar
- Community Solar Gardens
- Electric Power Distribution
- Energy Storage
- Electrifying Transportation
- Energy Conservation

EE–1703 Lab Content:

- Indoor Hydroponic Farming (with LEDs)
- Greenhouse Effect due to CO_2
- Simulating Electrical Fundamentals
- Internal Resistance of a Battery
- Photovoltaic Cells: iV Curve and MPP
- Photovoltaic Panels in Series and Parallel
- Economics of Rooftop Solar
- Economics of Community Solar Gardens
- Resistive and Electronic Dimming
- DC Motors
- Wind Turbines: iV Curve and MPP

Lab 1: Indoor Hydroponic Farming



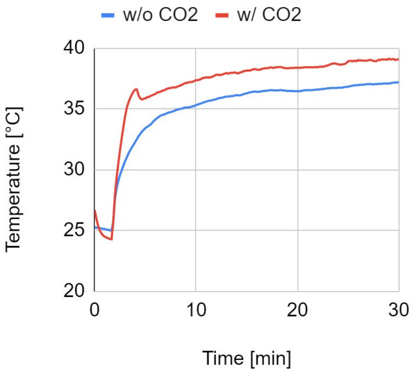
Summary

- Students grow lettuce indoors using deep-water hydroponics
- Electricity, water, and nutrient usage are tracked
- Recurring labor hours (monitoring and replenishment of nutrient solution, pruning, adjustment of the light) are tracked

Learning Objectives

- Demonstrate how plants can be grown indoors using LED lighting
- Investigate the cost components of growing produce and determine which one(s) are the primary drivers of the price

Lab 2: Greenhouse Effect due to CO_2



New Implementation for Fall 2023!

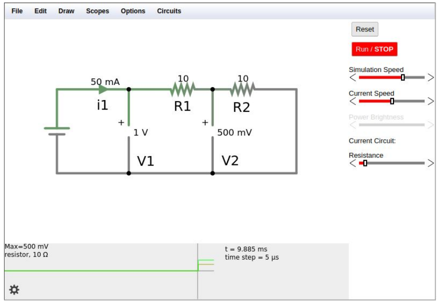
Summary

- Students measure temperature in a pair of sealed bottles
- Incandescent lamps used to add heat to the system
- Reaction of vinegar with baking soda used to generate CO_2 in one of the two bottles
- Students compare heating curves with and without CO_2

Learning Objectives

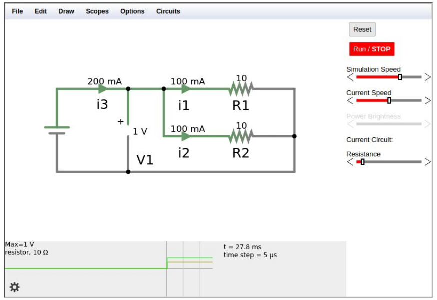
- Demonstrate how the presence of CO_2 acts as additional insulation, leading to higher temperatures in the bottles

Lab 3: Simulating Electrical Fundamentals



Summary

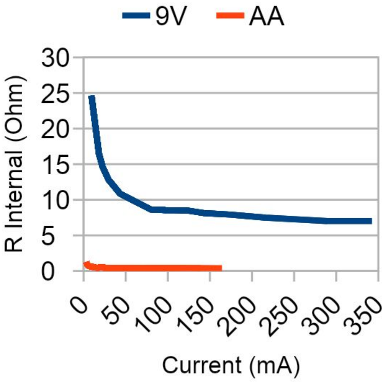
- Students use the Falstad circuit simulator to simulate ideal voltage sources, voltage and current sensors, and resistances in series and parallel
- https://www.falstad.com/circuit/



Learning Objectives

- Understand voltage, current, and resistance (Ohm's Law)
- Understand the behavior of resistances in series and parallel
- Calculate equivalent resistances in series and parallel
- Learn to use a simple circuit simulator

Lab 4: Internal Resistance of a Battery



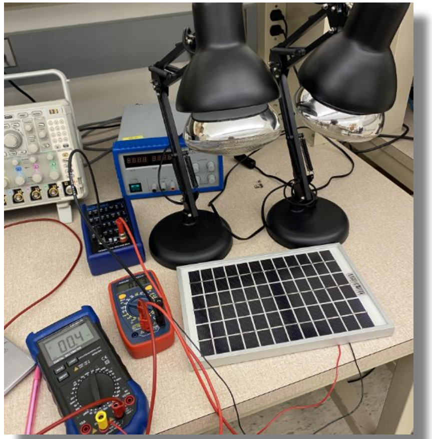
Summary

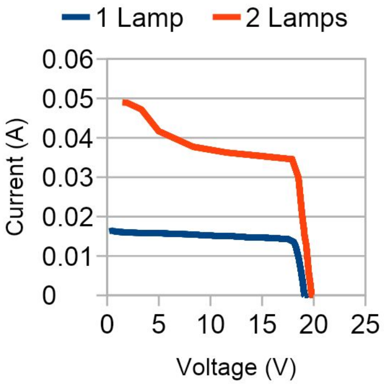
- Students load 9V and AA batteries across a range of resistance values using a decade resistance box
- Students use measurements of the terminal voltage and current to estimate the internal resistance of the battery

Learning Objectives

- Understand the concepts of electrical power and energy
- Learn how to use a multimeter for measuring voltage and current
- Understand how internal resistance leads to changes in the terminal voltage under load
- Understand how internal resistance decreases usable energy

Lab 5: Photovoltaic Cells: iV Curve and MPP





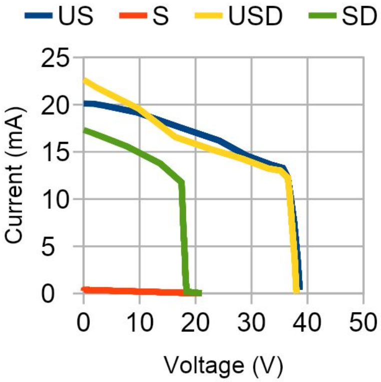
Summary

- Students map out the iV curve for a solar panel at 2 different light intensities (one and two lamps)
- Students plot the PV curve at both light intensities and locate the point where maximum power is generated

Learning Objectives

- Understand the basics of photovoltaic (PV) panels
- Understand the importance of the iV characteristic curve and how to find it experimentally
- Understand the importance of the maximum power point (MPP) and how to find it

Lab 6: Photovoltaic Cells in Series and Parallel



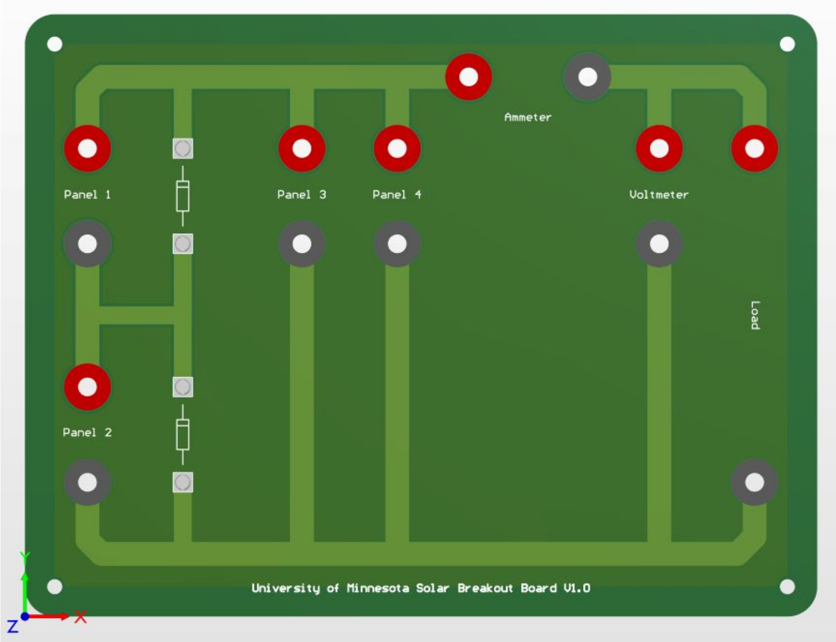
Summary

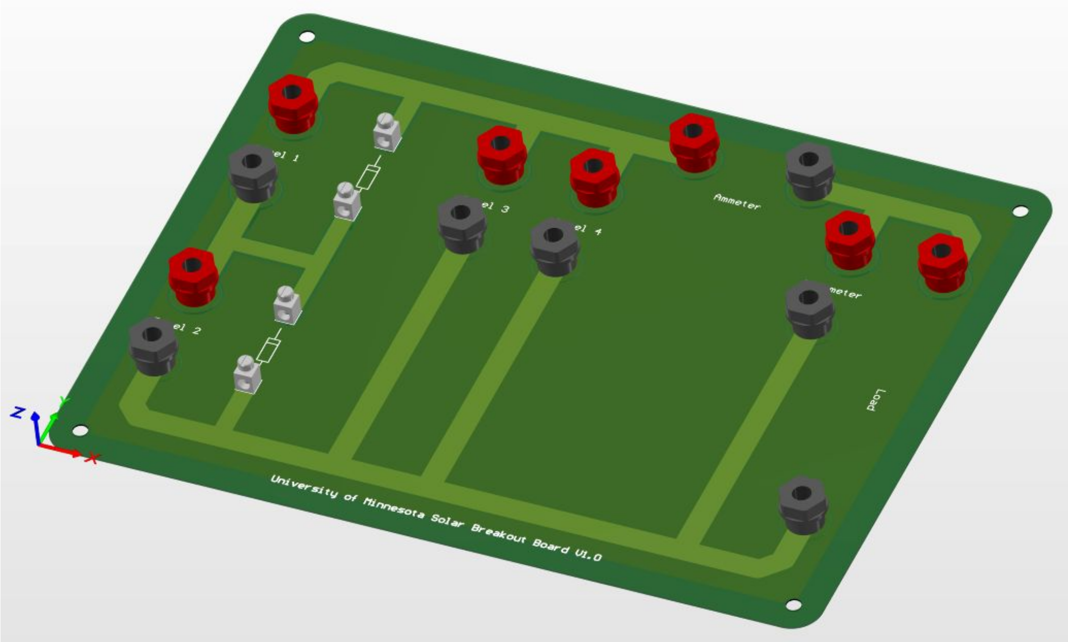
- Students map out the iV curve for a pair of solar panels connected in series, with and without shading, and with and without bypass diodes
- Experiment is repeated with the panels connected in parallel, with and without shading, and with and without a bypass diode

Learning Objectives

- Understand the effect on the combined iV curve of connecting photovoltaic panels in both series and parallel
- Understand the importance of bypass diodes when panels are connected in series

New Equipment: Solar Breakout Board

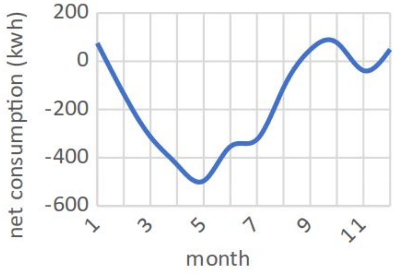




Objective: Streamline wiring for the two solar power labs.

Available Fall 2023

Lab 7: Economics of Rooftop Solar



Summary

- Students first size a solar array based on an assumed yearly load profile (provided) and mean hours of sun per day (from an online calculator)
- Students then compare the economics of paying for the system up-front vs paying for the system using a loan

Learning Objectives

- Understand the primary factors (technical and economic) when considering installation of rooftop solar power
- Understand up-front cost, payback interval, net economic benefit

Lab 8: Economics of Community Solar Gardens

Year	Electricity Rate	Yearly Electricity Cost for Non-Subscriber	Excel Credit	CSG Fee	Yearly Electricity Cost for Subscriber	Yearly Savings for Subscriber	Cumulative Savings
-	$/kW-h	$	$/kW-h	$/kW-h	$	$	%
1	$0.12	$1,080.76	$0.15	$0.13	$938.31	$142.45	$142.45
2	$0.12	$1,110.48	$0.15	$0.14	$938.31	$172.17	$314.62
3	$0.13	$1,141.02	$0.15	$0.14	$957.55	$183.46	$498.09
4	$0.13	$1,172.40	$0.16	$0.14	$977.18	$195.22	$693.30
5	$0.13	$1,204.64	$0.16	$0.15	$997.19	$207.45	$900.75
6	$0.14	$1,237.77	$0.17	$0.15	$1,017.59	$220.18	$1,120.93
7	$0.14	$1,271.80	$0.17	$0.15	$1,038.39	$233.41	$1,354.34
8	$0.15	$1,306.78	$0.18	$0.16	$1,059.60	$247.18	$1,601.52
9	$0.15	$1,342.71	$0.18	$0.16	$1,081.22	$261.49	$1,863.02
10	$0.15	$1,379.64	$0.19	$0.16	$1,103.26	$276.38	$2,139.39
11	$0.16	$1,417.58	$0.19	$0.17	$1,125.74	$291.84	$2,431.24
12	$0.16	$1,456.56	$0.20	$0.17	$1,148.65	$307.92	$2,739.15
13	$0.17	$1,496.62	$0.20	$0.17	$1,172.00	$324.62	$3,063.77
14	$0.17	$1,537.78	$0.21	$0.18	$1,195.81	$341.97	$3,405.73
15	$0.18	$1,580.06	$0.21	$0.18	$1,220.08	$359.98	$3,765.72
16	$0.18	$1,623.52	$0.22	$0.19	$1,244.82	$378.70	$4,144.42
17	$0.19	$1,668.16	$0.23	$0.19	$1,270.03	$398.13	$4,542.54
18	$0.19	$1,714.04	$0.23	$0.20	$1,295.74	$418.30	$4,960.85
19	$0.20	$1,761.17	$0.24	$0.20	$1,321.93	$439.24	$5,400.09
20	$0.20	$1,809.61	$0.24	$0.20	$1,348.63	$460.97	$5,861.06
21	$0.21	$1,859.37	$0.25	$0.21	$1,375.84	$483.53	$6,344.59
22	$0.21	$1,910.50	$0.26	$0.21	$1,403.58	$506.92	$6,851.51
23	$0.22	$1,963.04	$0.27	$0.22	$1,431.84	$531.20	$7,382.71
24	$0.22	$2,017.02	$0.27	$0.22	$1,460.64	$556.38	$7,939.09
25	$0.23	$2,072.49	$0.28	$0.23	$1,490.00	$582.50	$8,521.59

As mentioned in the worksheet, if the contract is terminated before it is over (before 25 years) the subscriber will need to pay for the next year as well. The following value takes this into account when calculating the total savings over time.
*The termination fee is 0 if the years of subscription is set to 25.

	Value	Unit
Savings (With Termination)*	$8,521.59	$

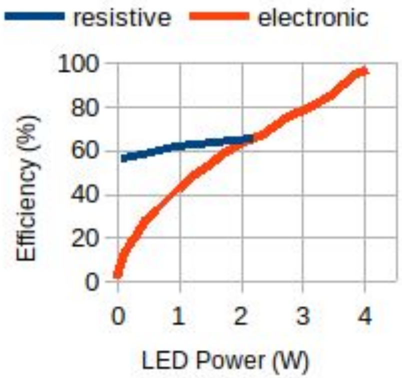
Summary

- An assumed yearly load profile and mean hours of sun per day are used as inputs
- Students use a spreadsheet to calculate the cumulative savings in electricity costs over a 25-year period based on different assumptions about the prices/credits and inflation of those prices/credits

Learning Objectives

- Learn about community solar gardens
- Use a spreadsheet to explore the financial benefits of subscribing to a community solar garden

Lab 9: Resistive and Electronic Dimming



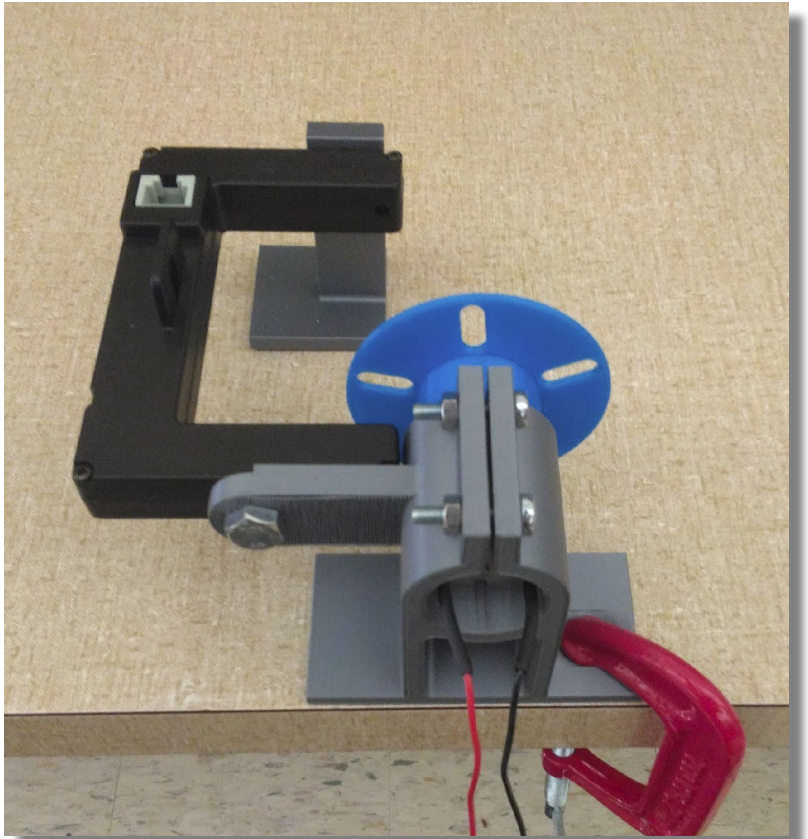
Summary

- Students use a DC power supply to map out the iV curve for an LED panel
- Students evaluate the efficiency of a resistive dimmer and an electronic dimmer used to power the LED panel

Learning Objectives

- Map out the iV curve for an LED panel
- Understand resistive dimming
- Understand electronic dimming using pulse-width modulation
- Understand that efficiency is a function of operating point and that the best option may depend on the operating point

Lab 10: DC Motors - Speed vs Voltage



Summary

- Students use a photogate sensor to measure the no-load speed for a DC motor as a function of voltage

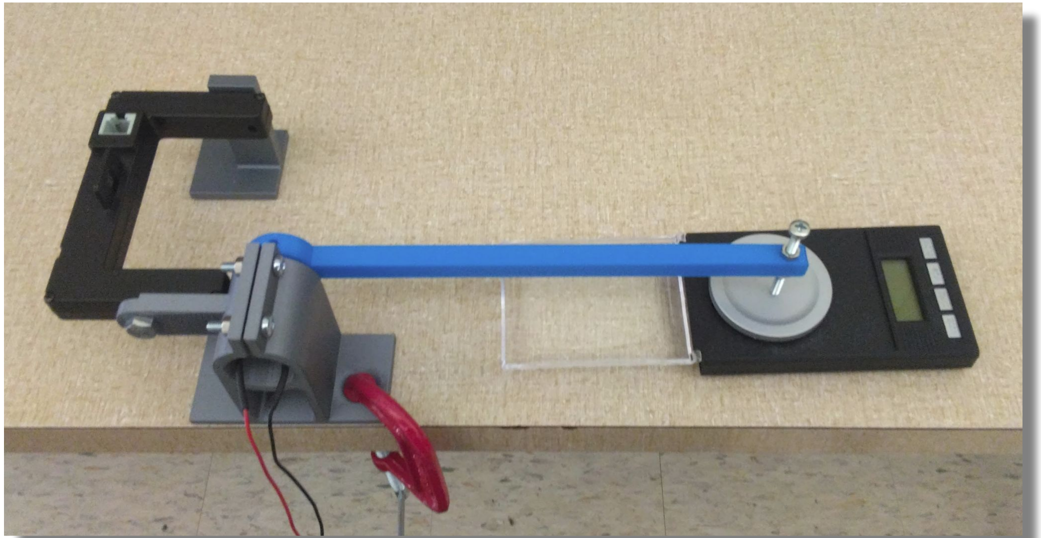
Learning Objectives

- Understand the voltage equation (steady-state) for DC motors
- Experimentally determine the voltage constant for a DC motor

Lab 10: DC Motors - Torque vs Current

Summary

- Students use a lever arm and digital scale to measure the stall torque of a DC motor as a function of current



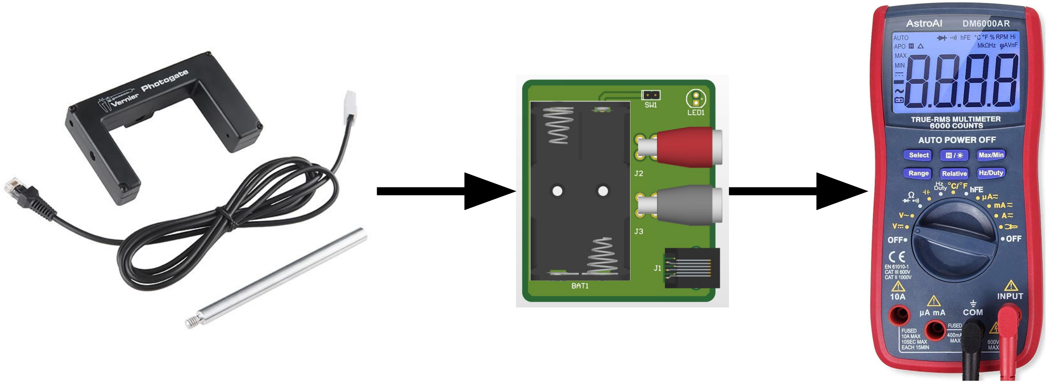
Learning Objectives

- Understand the torque equation
- Experimentally determine the torque constant for a DC motor

New Equipment: Photogate/Multimeter Adapter

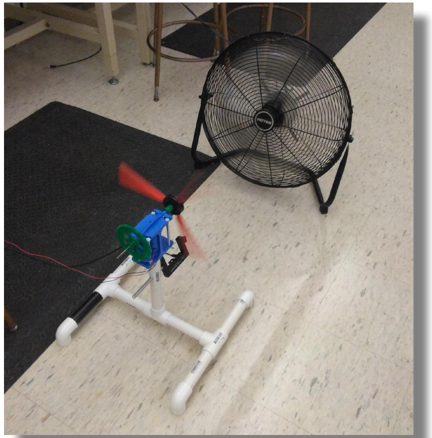
Objective:

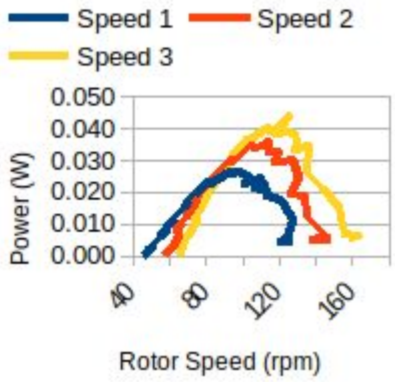
Enable motor speed measurement using a photogate sensor + multimeter as an alternative to using the Vernier LabPro / LabQuest and Logger Pro software.



Available Fall 2023

Lab 11: Wind Turbines: iV Curve and MPP





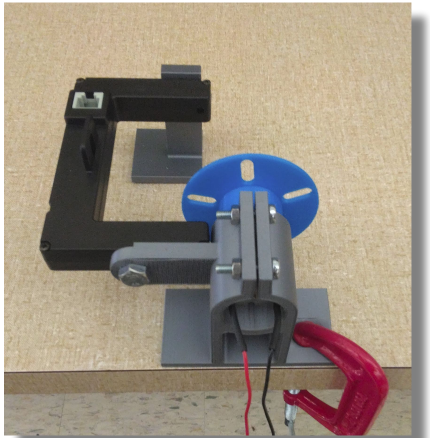
Summary

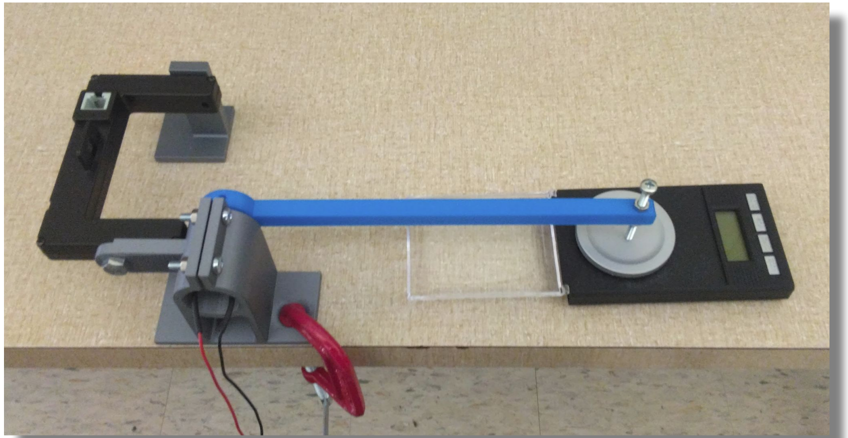
- Students use a fan and turbine (with a DC motor as the generator) to simulate a wind-turbine generator system
- A decade resistance box is used to sweep the load for the generator to map out the iV curve
- Power vs rotor speed is captured at 3 different fan speeds

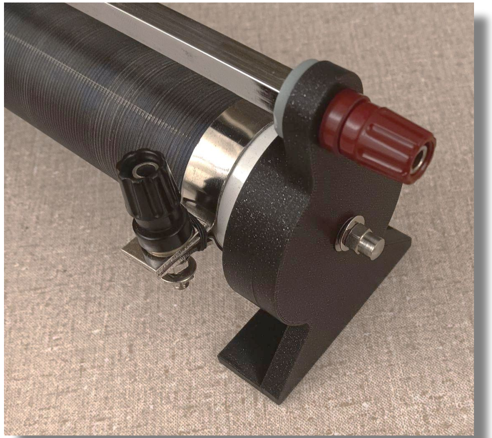
Learning Objectives

- Demonstrate that DC motors can also be used as generators
- Understand how the iV curve for a wind-turbine generator varies with both load and wind speed
- Understand how to find the maximum power point

Leveraging 3D Printing:







EE-1701 / 1703 Availability

This course was last offered at UMN during the **Fall 2022** semester.

This course will next be offered at UMN during the **Fall 2023** semester.

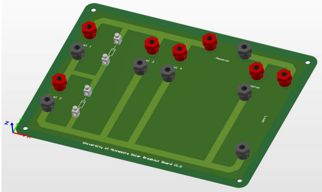
Lab course content may be found at:

https://cusp.umn.edu/courses/renewable-energy/climate-crisis-implementing-solutions

This includes:

- student manual
- equipment list
- stl files for 3D printed equipment

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”
- I would like to acknowledge Andy Petouvis, one of our 2023 summer interns, for his work on the solar breakout board. Andy will be a Senior this fall at Minnetonka High School.