Energy Mechanics and Applications of Modeling

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Fall 2021
Tuesdays, 5:15 – 6:45 PM
Location TBA

Course Description:
Introduction to mechanisms of energy technologies, energy consumption modeling, and grid implementation with an emphasis in renewables. The course is tailored to those with an interest in tech who desire to learn more about applications of engineering and software in the world of energy, but all are welcome to enroll.

Objectives:
Students will achieve an intermediate understanding of energy system mechanisms while being intellectually stimulated to approach novel ways of interpreting energy in a scientific context.

Required Texts:
Clean Energy Justice: Charting an Emerging Agenda
https://harvardelr.com/wp-content/uploads/sites/12/2019/08/43.2-Welton-Eisen.pdf

The Future of the Electric Grid:
https://sakai.duke.edu/access/lessonbuilder/item/916852/group/b875943b-9916-45df-9bc2-45d9030824b1/Readings/Future%20of%20the%20Electric%20Grid.pdf

Introduction to Engineering and the Environment:
https://sakai.duke.edu/access/lessonbuilder/item/916864/group/b875943b-9916-45df-9bc2-45d9030824b1/Readings/Intro%20to%20Eng%20and%20the%20Env%20Ch5.pdf

The Future of Solar Energy:
https://sakai.duke.edu/access/lessonbuilder/item/916946/group/b875943b-9916-45df-9bc2-45d9030824b1/Readings/Future%20of%20Solar%20Energy.pdf

Energy Systems Engineering:
https://sakai.duke.edu/access/lessonbuilder/item/916867/group/b875943b-9916-45df-9bc2-45d9030824b1/Readings/Energy%20Systems%20Engineering%20Ch13.pdf

Electricity Storage Handbook:
https://sakai.duke.edu/access/lessonbuilder/item/933919/group/b875943b-9916-45df-9bc2-45d9030824b1/Readings/DOE%20EPRI%20Electricity%20Storage%20Handbook.pdf

Fundamentals of Power System Economics
https://ebookcentral.proquest.com/lib/duke/reader.action?docID=219775

Additional smaller readings will be listed in the syllabus by date.

Course Requirements:
House Courses are graded on the S/U basis.

A grade of satisfactory in this course requires satisfactory completion of all assignments of this course including written assignments, attendance, and weekly participation. Students are required to attend at least 11 classes to receive a passing grade.

The course will include one midterm paper asking students to analyze the advantages and disadvantages of a renewable energy technology of student choice in implementation for the US grid and implementation in a nation with a developing energy infrastructure. This paper will be due October 26th and be approximately four pages double spaced.

There will also be one final modeling assignment. Students will model a renewable technology of their choice to join a grid with a NGCC plant and answer a variety of questions to provoke thoughtful analysis of their model. This final paper will be due by December 7th.

Course Schedule:

*Note: * next to class date denotes date of faculty sponsor attendance.*

Week 1 Electricity Foundations

08/24 Activity/Discussion: Introduction to DC and AC electricity and current, how they differ, and how to understand and quantify electrical terms, like voltage, current, resistance, and power.

Readings:

Clean Energy Justice pp. 308 - 361

https://learn.sparkfun.com/tutorials/voltage-current-resistance-and-ohms-law/all

(Electricity terminology introduction)

Week 2 The Electrical Grid

08/31* ***Faculty Sponsor attending (Dr. Dalia Patiño Echeverri)***

Activity/Discussion: Building upon terminology and material from the previous week, we will discuss how modern grids function with alternating current. We will specifically discuss the necessity of grid frequency with live examples like the Texas ERCOT blackouts in February 2021, reactive power versus real power load, and the differences among apparent, real, and reactive power.

Readings:

Future of the Electric Grid pp. 1-30, 235-260

No, The Blackouts In Texas Weren't Caused By Renewables. Here's What Really Happened:
https://www.npr.org/sections/live-updates-winter-storms-2021/2021/02/18/968967137/no-the-blackouts-in-texas-werent-caused-by-renewables-heres-what-really-happened

Texas Power Grid Was Minutes From Collapse During Freeze, Operator Says:
https://www.wsj.com/articles/texas-power-grid-was-minutes-from-collapse-during-freeze-operator-says-11614202063

Week 3 Turbine Generators

09/07 Activity/Discussion: Here we will discuss how turbine generators work. We will begin with terminology like nameplate capacity, capacity factor, and heat rate to understand the basics of how generators function, and then, we will dive into how prime movers derived from fossil fuels spin turbines, which in turn generate electricity for the grid. We will also go over example calculations for calculating plant annual generation.

Readings:

Introduction to Engineering and the Environment pp. 162 - 210
Natural Gas Combined Cycle How It Works: https://www.tva.com/Energy/Our-Power-System/Natural-Gas/How-a-Combined-Cycle-Power-Plant-Works

Week 4 ***Emissions Control***

10/14 Activity/Discussion: We will discuss the disadvantages and environmental impact of fossil fuel generators, specifically talking about NOx, Particulate Matter, and CO2 emissions. We will then dive into the mechanisms of specific technologies that have been implemented, such as Carbon Capture and Sequestration (CCS), and the specific advantages and disadvantages of those technologies and why there is a push for renewable technologies.

Readings:

Impact of Coal-fired Power Plant Emissions on Children's Health: A Systematic Review of the Epidemiological Literature (PDF is available for free online)
The outlook for improved carbon capture technology pp. 1-42: https://sakai.duke.edu/access/lessonbuilder/item/916833/group/b875943b-9916-45df-9bc2-45d9030824b1/Readings/The%20Outlook%20for%20Improved%20Carbon%20Capture%20Technology.pdf

Week 5 ***Wind and Hydro Generation***

09/21 Activity/Discussion: We will discuss how wind generation works by talking about why wind turbines are constructed and situated in specific manners. We will then calculate the power generation of a wind turbine by understanding the variables involved for calculating rotor speed. We will also talk briefly about hydro generation, how to calculate power generation, and discuss why hydroelectric dams may not be considered an ideal form of renewable/clean energy.

Readings:

Energy Systems Engineering pp. 399 - 443
A natural experiment reveals the impact of hydroelectric dams on the estuaries of tropical rivers: https://advances.sciencemag.org/content/5/3/eaau9875

Week 6 ***Photovoltaic Solar – Irradiance***

09/28* We will begin this two phase portion of Solar PV by first discussing what solar irradiance is, its value for solar PV, and how to calculate the given irradiance in a certain space. We will conclude with discussing fixed, single axis, and two-axis PV systems and how to calculate the optimal tilt angle for a solar PV module.

Readings:

The Future of Solar Technology pp. 1-47
PVEducation Chapter 2: https://www.pveducation.org/pvcdrom/properties-of-sunlight/basics-of-light

Week 7 ***Photovoltaic Solar - Engineering***

10/05 Activity/Discussion: For the second portion of solar PV, we will discuss the semiconductor attributes of solar and how the physics and engineering works within solar panels. We will also discuss a variety of solar technologies including up and coming designs such as organics and perovskite, and how they technologically differ from common silicon solar panels to deliver higher efficiency rates.

Readings:

PVEducation Chapters 3 and 4: https://www.pveducation.org/pvcdrom/pn-junctions/introduction-to-semiconductors
Organic Photovoltaics: https://www.sigmaaldrich.com/materials-science/organic-electronics/opv-tutorial.html

Perovskite and other novel PV: https://www.nature.com/articles/d41586-019-01985-y

Week 8 Battery Electrochemistry and Solar Storage
10/12 Activity/Discussion: We will primarily discuss battery storage and the physics and electrochemistry of batteries. We will also discuss the challenges with battery storage of electricity for solar. We will also talk about alternative methods of energy storage for solar.

Readings:
Electricity Storage Handbook pp. 29-50, 76-111

Week 9 Hydrogen Fuel
10/19 Activity/Discussion: We will discuss how hydrogen fuel is created and the mechanics of hydrogen fuel generators and vehicles. We will also discuss the downsides for hydrogen fuel creation and recent developments in the space of creating hydrogen with renewables through electrolysis.

Readings:
So, What Exactly is Green Hydrogen?:
https://sakai.duke.edu/access/lessonbuilder/item/917508/group/b875943b-9916-45df-9bc2-45d9030824b1/Readings/So%20What%20Exactly%20Is%20Green%20Hydrogen.pdf
Renewable Energy Storage Using Electrolysis: https://www.pnas.org/content/117/23/12558
Hydrogen Fuel Cell Technology for the Sustainable Future of Stationary Applications (online PDF available)
Hydrogen Fuel Cell Vehicles; Current Status and Future Prospect (online PDF available)

Week 10* Smart Grids – Modeling
Faculty Sponsor attending (Dr. Dalia Patiño Echeverri)
10/26* Activity/Discussion: We will discuss how plants are scheduled based on the costs of electricity and capacity to meet the load of the grid at any given time. We will do an exercise utilizing eGrid data to create a model showing generators of various types in the order they will be scheduled based on electricity cost. We will conclude with a discussion on how smart meters work.

Prompt #1 due:
You are a consultant for a power utility in the Northeastern United States. A fictional coastal county, Treezy, seeks to install a novel form of clean energy to install to replace a 100 MW coal plant, but is unsure whether the best method is to move forward with retrofitting the coal plant with a carbon capture system or develop a new generator in its place, like a solar or wind project.

At the same time, your friend is working on an energy access project in West Africa, and is also considering the same solutions and wants your input (instead of retrofitting a 100 MW coal plant, they are considering building a new IGCC plant).

Discuss the advantages and disadvantages to all the possible solutions and what specifically you would choose to implement in the county of Treezy and then how your analysis would differ for your friend's project.

The paper should be 4 pages double-spaced with Times New Roman Size 12 font.

Readings:

Smart Meter Based on Real Time Pricing pp. 1-5:
https://www.sciencedirect.com/science/article/pii/S2212017315002467
Smart Grid: A Brief Assessment of the Smart Grid Technologies for Modern Power System pp. 1-22 (online PDF)
Fundamentals of Power System Economics pp. 1-24

Week 11 Basics of Linear Programming

11/02 Activity/Discussion: There will be a short lecture on linear programming basics detailing how to solve basic optimization problems involving energy by graphing and utilizing excel. Students will then work together to complete cost optimization problems to hone skills. We will then discuss how to utilize the recent knowledge to build certain constraints for modeling an example generator to meet grid demand.

Readings:

Linear Programming Introduction pp. 1-24: https://sakai.duke.edu/access/content/group/def8fa8d-2e57-4369-883a-87edbfb13f9c/Readings/RR11-Bazaraa%20Ch1.pdf
Optimization Technology for Energy and Power pp. 1-26:
https://sakai.duke.edu/access/content/group/def8fa8d-2e57-4369-883a-87edbfb13f9c/Readings/RR9-Optimization_Technology_for_Energy_and_Power.pdf

Week 12 Mixed Integer Linear Programming

11/09 Activity/Discussion: As a continuation from basic linear programming, we will discuss the addition of binary variables and how to represent them in a linear program. Students will work on a few optimization problems together with binary variables and we will conclude with finishing the generator model from last class by adding the binary constraints.

Assignments:

Readings:

The Peoples Gas Light and Coke Company Plans Gas Supply pp. 1-13:
https://sakai.duke.edu/access/content/group/def8fa8d-2e57-4369-883a-87edbfb13f9c/Readings/RR26-Planning%20gas%20supply.pdf
Northern Hydroelectric Development in an Optimal Expansion Program for Ontario Hydro pp. 1-12:
https://sakai.duke.edu/access/content/group/def8fa8d-2e57-4369-883a-87edbfb13f9c/Readings/RR16-power%20planning%20ontario.pdf
A Flexible Ramping Capacity Model for Generation Scheduling with High Levels of Wind Energy Penetration pp. 1-17 (Online PDF)
Flexible Operation of Batteries in Power System Scheduling with Renewable Energy pp. 1-12:
https://www.osti.gov/servlets/purl/1365839

Week 13 Grid Networks

11/16 Activity/Discussion: The final discussions will entail how to model the electricity path with all the knowledge from previous classes in electricity foundations, generator mechanics, and generator demand modeling. Students will work together to create a formulation for modeling a microgrid.

Week 14 Grid Networks Continued

Faculty Sponsor attending (Dr. Dalia Patiño Echeverri)
11/30* Activity/Discussion: A continuation of Week 13's activity of creating a model for microgrid.

12/7 Prompt #2 Due:
Refer back to Prompt #1 where you selected a specific technology to implement into the grid. You will now formulate a linear program to meet the grid demand when paired with a natural gas combined cycle plant. The parameters that your NGCC plant and the technology of your choice will consist of at least these variables:

Online cost of generating unit, shut-down cost of generating unit, start-up cost of generating unit, variable cost of generating unit, power generation capacity of unit, minimum power output of unit, ramping-down limit of generating unit, shut-down ramping limit of generating unit, start-up ramping limit of generating unit, ramping-up limit of generating unit, and power demand at a given time t.

Feel free to add additional variables like sale value of electricity if it helps you choose a specific type of formulation.

a. Write the formulation with objective function minimizing or maximizing a Z value of your choice. Write the constraints in terms of variables only. Declare the decision variables and parameters before you write your formulation.
b. Explain how you set up your objective function and why it is optimizing the value you chose.
c. Explain the purpose of each constraint.
d. Speculate what might be the values of the variables for your technology, such as ramp up limit, ramp down limit, start up cost, etc.