ME809 Optical Simulation Methods for Concentrating Solar Energy Applications 3-0-1 4

Year of introduction: 2021

Course Objective:
The course is intended to teach students how to utilize optical ray tracing to model, simulate, and analyze solar energy systems, especially concentrating solar thermal energy systems. These complex, multi-element systems are difficult or impossible to evalate without the use of ray-tracing software.

Course Outcomes:
CO1 : Ability to design and simulate the optical properties of various multi-element 2D and 3D concentrating solar energy systems to determine the resultant optical flux and its properties on the solar energy receiver(s), primarily using optical ray-tracing methods in OpticStudio by Zemax.
CO2 : Understand how to perform optimization of solar energy systems to enhance the solar energy collected at the receiver(s).
CO3 : Study how modelling, simulation and optimization can be used in "Power Tower" systems to minimize the undesired effects of heliostat blocking and shading.
CO4 : Ability to perform independent research on solar energy systems and present in written and oral formats

Modules:
Introduction: History of solar energy; Modern implementation and penetration in today's market; Future opportunities and areas of growth

Solar Optics Fundaments: The sun as a light source; Direct light; Diffuse light; Atmospheric effects; Scattering; Attenuation; Cosine law; Measurement and coordinate systems

Simulation and Modelling Tools: Statistical Analysis; Matrices; Ray Tracing; Monte Carlo; OpticStudio; Source characterization; Atmospheric effects; Elements; Mirrors; Apertures; Flux maps; Scatter plots; Payback time; Levelized cost of energy

Solar Energy Systems: Solar photovoltaic; Concentrating solar photovoltaic; Solar thermal; Parabolic trough; Concentrating dish; Power tower; others

Concentrating and Tracking: 2-D and 3-D concentrating solar thermal; 2-D and 3-D tracking; Impact of axis orientation; Impact of tracking on energy production

Solar Position Algorithms: Deterministic algorithms; Sunlight sensors; Hybrid systems; Levels of complexity and accuracy; NREL SPA algorithm; Others

Heliostats: Azimuth/Elevation; Pitch/Roll; Target axis; Optical properites; Canting; Blocking; Shading;

Power Tower Systems: Heliostat field layout and algorithms; Types of receivers; Receiver optical and thermal properites; Aiming and focusing; Self learning algorithms; Optimization; Thermal storage;

Lab Exercises (to be conducted with OpticStudio software)

1) Simulate solar energy flux on a fixed solar PV panel at various azimuth and elevation angles relative to the sun at various fixed positions. Calculate corresponding electrical energy outputs.
2) Simulate a concentrating solar energy system by using an optical lens to focus solar rays on a solar PV cell. Using flux maps and a heat equation, derate performance and determine corresponding electrical output.
3) Simulate solar energy flux on a stationary, non-concentrating solar thermal collection device, integrated over a period of time using a solar position algorithm to determine the sun's position relative to the collector.
4) Using optical ray-tracing, determine the solar energy collected by a parabolic trough style solar thermal system (2D concentration with tracking). Integrate energy collection over a period of time using the solar position algorithm implemented earlier.
5) Using optical ray-tracing, determine the solar energy flux reflected from a heliostat onto a receiver. Integrate over time using a solar position algorithm.
6) Using optical ray-tracing, determine the solar energy flux reflected from multiple heliostats onto a receiver, showing the effects of heliostat blocking and shading and how they change throughout the day.

Project:
Using optical ray-tracing software and scripting, simulate a simple concentrating solar thermal "power tower" system, with multiple heliostats tracking the sun and reflecting light onto a central receiver. Perform integration and basic optimization to space the heliostats in such a way as to minimize blocking and shading while maximizing solar energy input at the receiver for a given space-constrained area.

Textbook:

1. W.B. Stine, R.W. Harrigan, "Solar Energy Systems Design", John Wiley and Sons, Inc., 1986
2. "Power from the Sun", https://www.powerfromthesun.net, William Stine and Michael Geyer, 2021 (Online, open, updated version of Solar Energy Systems Design)
3. Optical System Design, 2nd ed., Robert Fisher, MacGraw-Hill, 2008

References:

1. Perlin, John, "Let It Shine: The 6,000 Year Story of Solar Energy", New World Library, 2013
2. John J. Craig, "Introduction to Robotics: Mechanics and Control", Pearson Education, 2008
3. Introduction to Lens Design: With Practical Zemax Examples, Willmann-Bell, 2002
4. www.zemax.com

Prerequisites:

1. Linear algebra / vector algebra, College level calculus, College level Physics, Matlab programming or similar would be very helpful, Excel or similar

Pedagogy: Lecture material with lab type exercises to apply concepts in real-life scenarios through the use of scripting, ray-tracing, and analysis.

Evaluation Pattern:
40% Lab Exercises
60% Project

Activities/Content with direct bearing on Employability/ Entrepreneurship/ Skill development:
Learning to define, model, simulate and analyze systems, especially using ray tracing applied to solar energy systems