Fluid Mechanics of Renewable Energy: Wind, Wave and Tidal Energy

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Course Description

You will learn about the fluid mechanics of renewable energy resources; wind, tidal stream, tidal barrage and wave energy. For each you will consider the scale of the resource, how devices interact with the resource to extract power, leading device types and operating modes. You will learn about and derive simple and complex models of interaction with the flow field to demonstrate leading aspects of device-resource interaction, and thus understand the limits of power extraction for each energy resource.

For wind and tidal stream energy key concepts include lift and drag at a blade level, actuator disc theory, streamtube analysis, power and thrust coefficients, common engineering design methods and blade element momentum theory. Further lectures will address modes of operation, pitch versus stall regulation, tip losses, wakes, rotor design, blockage effects, channel dynamics. Gross energy potential and modes of operation of tidal barrage systems will also be examined. For wave energy you will learn about the hydrodynamics of wave energy devices with various prime movers (e.g. point absorbers, attenuators and terminators), the energy available in waves and the limits of energy extraction for point absorbers.

Learning Objectives

1. To develop a working understanding of how renewable energy devices extract energy from wind, waves and tidal resources.
2. To understand the mechanics of operation of the principal wind turbine types.
3. To be able to derive and use Blade Element Momentum theory to model the operation of axial flow wind turbines,
4. To understand how the tidal environment differs from the wind environment and the implications for tidal turbine design.
5. Determine the gross energy potential and deliverable power of tidal barrage installations operating under single or dual mode operating strategies.
6. Classify wave energy devices as to their mechanism of interaction with the flow-field, and describe the basic mechanisms of interaction with the wave field of leading device types.

Prerequisities

High school mathematics and Physics including Newton's Laws and Energy conservation.

Course material

Instructor's lecture slides in pdf format; referenced texts and academic papers.

Textbooks

Burton, Sharpe, Jenkins & Bossanyi, Wind Energy Handbook (2nd Edition), Wiley, 2011.

Grading Policy

Student performance in the class will be evaluated based on homework assignments, project presentation and final project report. Homework assignments will consist of analytic and mathematical modelling problems of wind, wave and tidal energy systems. The project presentation is an oral presentation accompanied with Power Point slides presented by all team members. The project report should be written in format provided by the instructor. The final grade will be assigned based on the following grading policy:

2 Homework assignments (20%)
1 Project presentation (30%)
1 Project report (50%)

Research Project

Students will work in groups of five on the design of a renewable energy system. Projects will include the assessment of the available resource, determination and selection of a suitable energy harvester (wind, wave or tidal energy convertor), modelling of the performance of the device, and calculation of the Annual Energy Yield of the device. Projects will range in complexity from the calculation of the energy in the resource through to aerodynamic design of modern wind turbine blades. Students will develop their own mathematical models using spreadsheets, python, MATLAB or similar. Using the lecture notes provided and the referenced reading material students will develop appropriate design solutions and energy yield estimates. The project report will include the background and motivation behind the proposed system, review of state-of-the art, analysis of the available resource, proposed energy system design, analysis and simulation results, discussion, suggestions for future work and conclusions.

Week (hours)	Lecture	Due
1 (3 hours)	Introduction and Course Overview The wind resource; Weibull distributions, velocity profiles, variability and turbulence. Mass, momentum and energy conservation in fluid mechanics. Actuator Disk Theory and the Betz limit for wind turbines. Performance coefficients. Principal wind turbine device types; advantages and disadvantages.	
2 (3 hours)	Blade Element Momentum theory. Aerodynamic design of wind turbine rotors. Control and operation of wind turbines; fixed and variable speed turbines, stall control, pitch-to-stall and pitch-to-feather control. Operation of modern wind turbines. Estimation of Annual Energy Yield.	Home Work Assignment 1
3 (3 hours)	The tidal environment and the available tidal resource. Principal tidal stream turbine device types. Blockage effects and channel dynamics for tidal steam turbines. Gross energy potential for tidal barrage installations. Ebb, flood and dual mode operation. The power within waves and the wave energy resource. Classification of wave energy devices and principal device types. Overview of wave energy device hydrodynamics.	Home Work Assignment 2
4 (3 hours)	Research discussions (individual group meetings 1 hour each)	Project design proposal
5 (3 hours)	Research discussions (individual group meetings 1 hour each)	Project update
6 (3 hours)	Research discussions (individual group meetings 1 hour each)	Project presentation and report