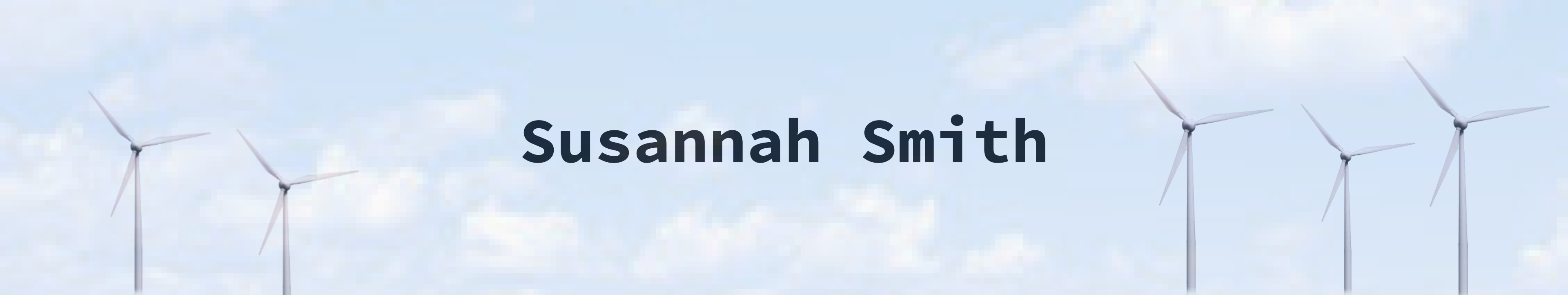
Improving Wind Turbine efficiency using Modelling and Analysis Software



Susannah Smith

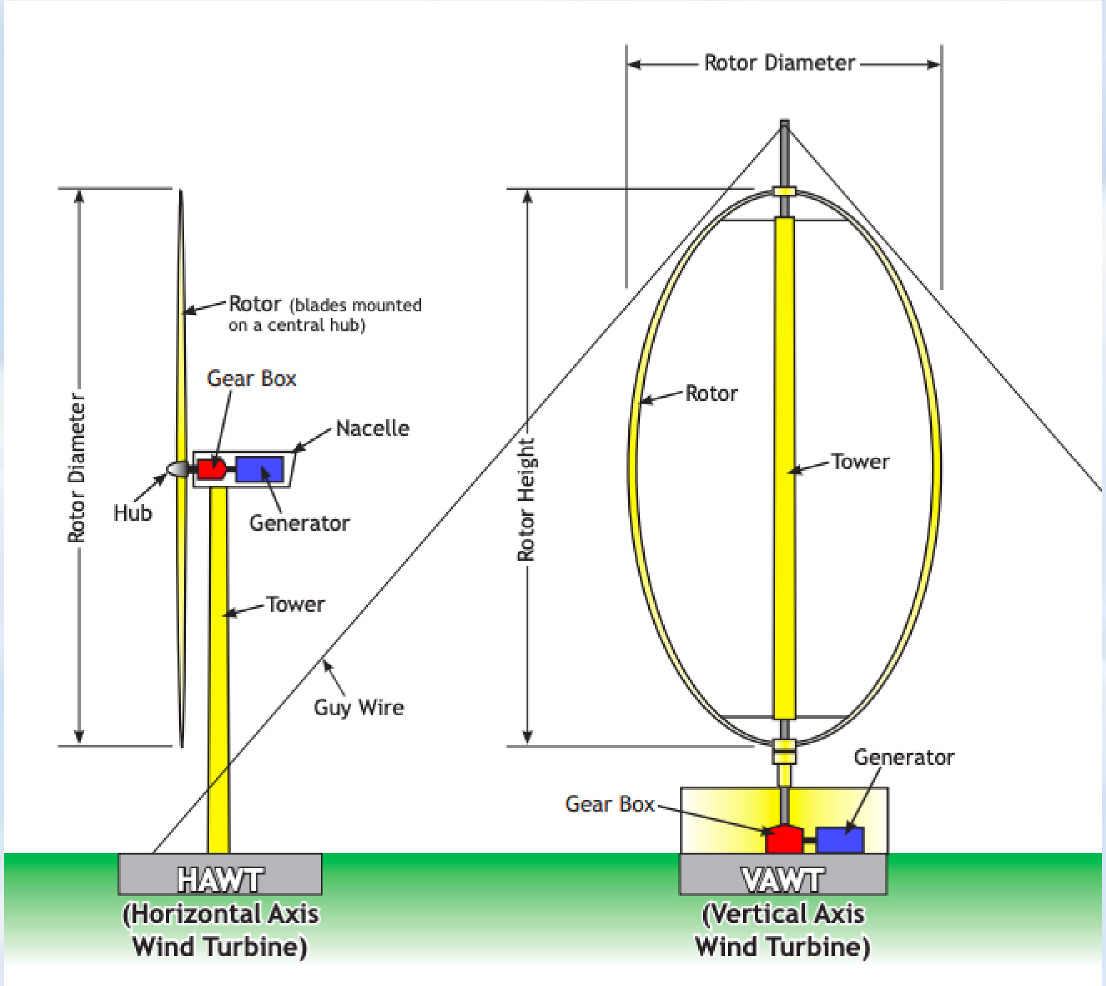
Renewable Energy

- Recent push for renewable energy research
  - Caused by extensive fossil fuel use
- Wind energy
  - Turbines (1)

https://energywatch-inc.com/renewable-energy-paradox/

Wind Turbines

- Mechanical energy is converted to electricity
- Types of turbines:
  - Horizontal axis
    - Blades rotate around an axis that is parallel to the ground
    - Most used/ commercially available
    - Upwind or downwind turbines
      - Zhou, H., & Wan, D. (2015). Numerical investigations on the aerodynamic performance of wind turbine: Downwind versus upwind configuration. Journal of Marine Science and Application, 14(1), 61-68. doi:10.1007/s11804-015-1295-9
  - Vertical axis
    - Axis is perpendicular to the ground
      - Craig, A. E., Dabiri, J. O., & Koseff, J. R. (2017). Low order physical models of vertical axis wind turbines. Journal of Renewable and Sustainable Energy, 9(1), 013306. doi:10.1063/1.4976983



https://teachergeek.org/wind_turbine_types.pdf

Turbine Analysis Software

- FLORIS
- WISDEM
- SOWFA
- FAST

FLORIS

- inexpensive, controls-oriented modeling tool of the wake characteristics in a wind farm (2)
- Methods for optimization and design of wind farm control and layout
- Annual energy production analysis
- Methods to model heterogeneous atmospheric conditions
- Coupling methods to other tools, including SOWFA (3)

WISDEM

- The Wind-Plant Integrated System Design & Engineering Model (WISDEM®) is a set of models for assessing the overall cost of energy of a wind power plant. The models use the wind turbine and plant cost and estimated energy production, as well as financial models, to estimate cost of energy WISDEM models include:
  - Rotor Aero
  - Rotor Structure
  - Nacelle Structure
  - Tower Structure
  - Turbine Costs
  - Plant Balance of System Costs
  - Plant Operating Expenses
  - Plant Energy Production
  - Plant Finance (4)

SOWFA

- computational fluid dynamics to allow users to investigate wind turbine and wind power plant performance under a full range of **atmospheric conditions** and **terrain**.
- examine and minimize the impact of turbine wakes on overall plant performance. (5)

https://www.rechargenews.com/wind/will-wind-wake-slow-industrys-ambitions-offshore-/2-1-699430

FAST

- Fatigue, Aerodynamics, Structures,and Turbulence
- Aeroelastic simulator capable of predicting both the extreme and fatigue loads of two- and three-bladed horizontal-axis wind turbines (HAWTs).
- FAST joins aerodynamics models, hydrodynamics models for offshore structures, control and electrical system dynamics models, and structural dynamics models to enable nonlinear aero- hydro-servo-elastic simulation in the time domain.(1, 6, 9)

Literature Review

Turbine blades are usually made of composite material, the base and other mechanisms are mostly steel or iron.

Mishnaevsky, L., Branner, K., Petersen, H., Beauson, J., Mcgugan, M., & Sørensen, B. (2017). Materials for Wind Turbine Blades: An Overview. Materials, 10(11), 1285. doi:10.3390/ma10111285

Part	Function	Materials used
Blade shell	Maintaining the blade shape, resisting the wind and gravitational forces	Strong, lightweight composites
Unsupported parts of the shell	Resisting the buckling load	Thickened sandwich structures with light core materials and multidirectional face laminates
Integral web, spars or box beam	Resisting the shell buckling/ shear stresses due to flapwise bending	Biaxial lay-ups at +/-45o,
Adhesive layers between composite plies, and the web and the blade shell	Ensuring the out-of plane strength and stiffness of the blade	Strong and highly adhesive matrix

https://www.semanticscholar.org/paper/COMPOSITE-MATERIALS-IN-WIND-ENERGY-TECHNOLOGY-Mishnaevsky/bc7e9ec179520b2aab1c6366dc6a4aa76e864b01

Literature Review

Different types of turbines, vertical vs horizontal

Craig, A. E., Dabiri, J. O., & Koseff, J. R. (2017). Low order physical models of vertical axis wind turbines. Journal of Renewable and Sustainable Energy, 9(1), 013306. doi:10.1063/1.4976983

https://c03.apogee.net/mvc/home/hes/land/el?utilityname=screc&spc=kids&id=16214

Horizontal Axis Vertical Axis

Literature Review

Optimal farm layout using global wind farm cost model using the initial investment and the present value of the yearly net cash flow during the entire wind-farm life span

Optimization of wind farm turbines layout using an evolutive algorithm Javier Serrano Gonzalez a , Angel G. Gonzalez Rodriguez b , Jose´ Castro Mora c , Jesu´ s Riquelme Santos a,*, Manuel Burgos Payan
https://doi.org/10.1016/j.renene.2010.01.010

Gap in the Research

- Programs have vast capabilities, not all have been explored in every context
  - Individual turbines
  - Farms
  - Materials
  - Locations

How can wind turbine design by optimized using OpenFAST?

I hypothesize that I will be able to adjust the blades, generator torque, brakes, and nacelle to improve efficiency using simulation and linearization.

Methodology for OpenFAST

- two different forms of operation/ analysis modes
    - Simulation
    - Linearization

Methodology for OpenFAST

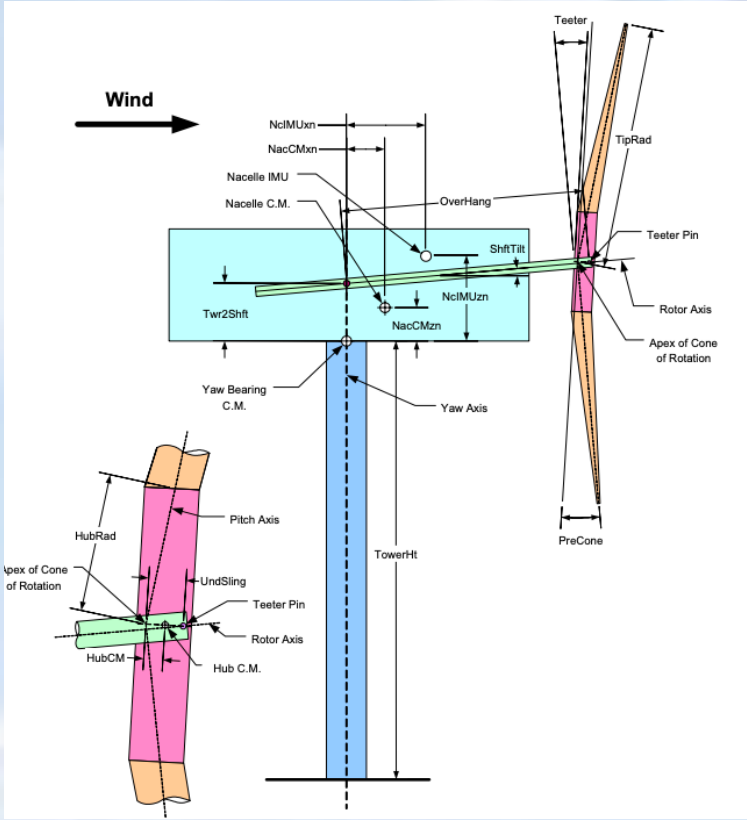
- Simulation
  - aerodynamic and structural response to wind-inflow conditions is determined in time.
  - active controls modified
  - predict both the extreme and fatigue loads of HAWT
  - Windows executable program file or DLL interfaced with Simulink

Methodology for OpenFAST

- Linearization
  - Extracting linearized representations of the complete nonlinear aeroelastic wind turbine modeled
  - aid in controls design and analysis

Simulation

- The model for two bladed turbines relates nine rigid bodies (earth, support platform, base plate, nacelle, armature, gears, hub, tail, and structure furling with the rotor) and four flexible bodies (tower, two blades, and drive shaft) through 22 degrees of freedom (DOFs).

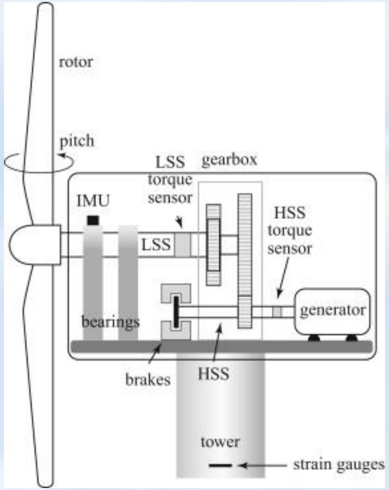


Simulation

Controls:

- pitching the blades
- controlling the generator torque
- applying the HSS brake
- deploying the tip brakes
- yawing the nacelle

- setting some of the appropriate input parameters in the Turbine Control section of the primary input file



Simulation

- Simulate special events
  - Starting turbine
  - Idling turbine
  - Blade failure
  - Disconnect from grid

Linearization

- capability of extracting linearized representations of the complete nonlinear aeroelastic wind turbine modeled in the code.
- It works by 1. computing a periodic steady state operating point condition for the DOFs and 2. numerically linearizing the FAST model about this operating point to form periodic state matrices.

Linearization

- First, determine an operating point to linearize the model about
- The calculation of an operating point depends on whether the rotor is spinning or stationary, whether the turbine is variable or constant speed, and whether the operating point is in Region 2 (below rated wind speed) or Region 3 (above rated wind speed).

Linearization

- Once a periodic steady state solution has been found, FAST numerically linearizes the complete nonlinear aeroelastic model about the operating point.
- post processing script file in MATLAB entitled Eigenanalysis.m.

FULL-SYSTEM LINEARIZATION FOR FLOATING OFFSHORE WIND TURBINES IN OPENFAST

Jason M Jonkman et al.

Robertson National Renewable Energy Laboratory

presents the development of the new linearization functionality of the open-source engineering tool OpenFAST for floating offshore wind turbines

FULL-SYSTEM LINEARIZATION FOR FLOATING OFFSHORE WIND TURBINES IN OPENFAST

- Concluded that linearization of the underlying nonlinear wind-system equations is important for understanding the system response and explained well-established methods and tools for analyzing linear systems.
- Limitations on the study are that implementation at the time of writing has not yet been completed enough to produce results on functionality

Discussion/ Future Research

- Mentor project on wakes
- Locations
    - Analog Ensemble

Sources

1. https://openfast.readthedocs.io/en/master/
2. https://windexchange.energy.gov/tools
3. https://floris.readthedocs.io/en/develop/
4. https://www.wind-energ-sci.net/3/819/2018/
5. https://www.nrel.gov/docs/fy15osti/63378.pdf
6. https://github.com/NREL/SOWFA/blob/master/README.SOWFA
7. https://www.nrel.gov/docs/fy19osti/71865.pdf
8. https://github.com/openfast/openfast
9. User manual PDF
10. https://www.nrel.gov/docs/fy19osti/71865.pdf

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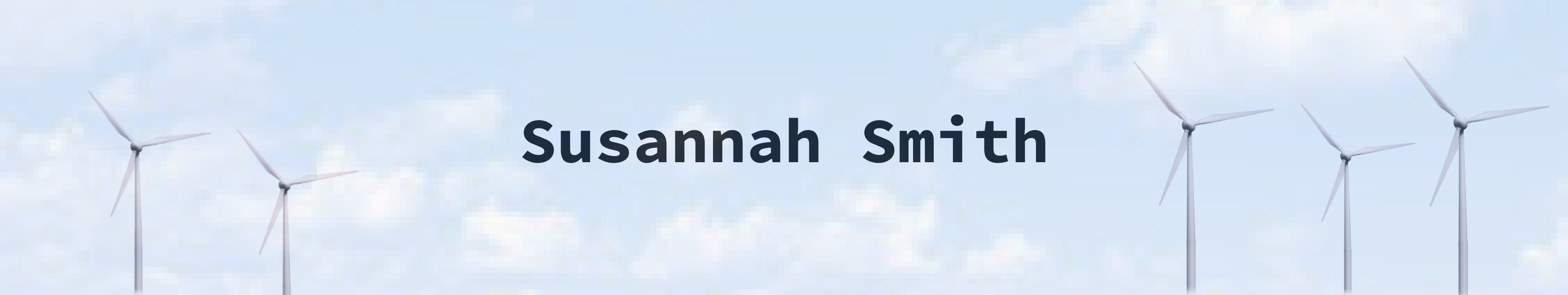

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