DER Project

Giacomo Macchiavello

Taken by me at Invenergy's Beech Ridge Wind Farm in West Virginia

Bio

- Born in Lima, Peru (naturalized 2023)
- Living in Virginia
- Attended Virginia Tech
- Materials Science & Engineering (Green Engineering, Politics, Philosophy, and Economics)
- Switched tracks from space systems to sustainability/renewables
- I speak Spanish, English, German (intermediate)
- Love soccer, backpacking/travel, cooking, photography/filmmaking (watch plotless French movie), snowboarding

Inspiration

- Exploring the Pastoruri Glacier in La Cordillera Blanca of the Andes near Huaraz, Peru
- Connected stories of its past to my experience & education in the US
- Instilling a sense of urgency in innovating solutions for the climate crisis

Taken by me at the Pastoruri Glacier

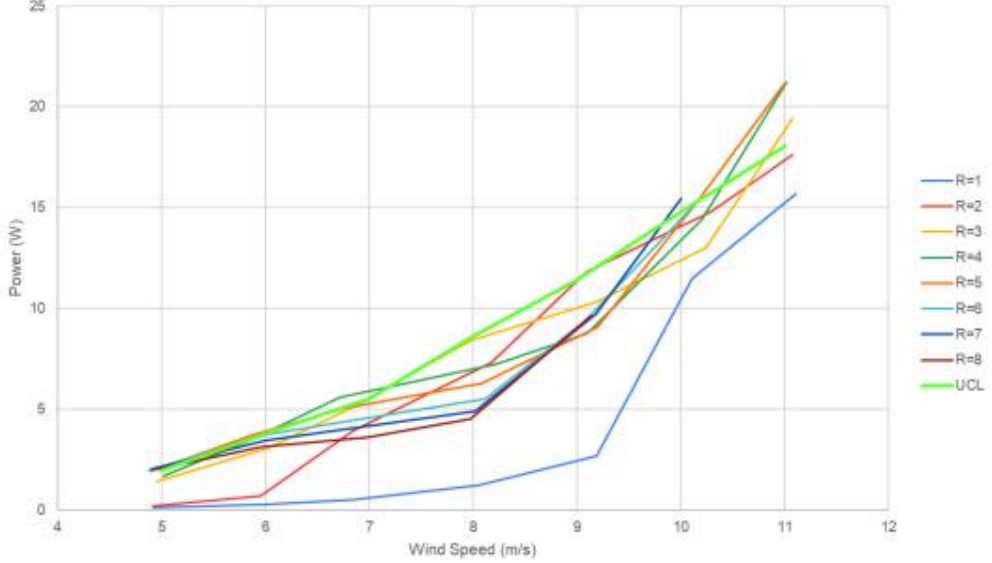
Microturbine Design

Table of Contents

Mission Statement & Milestones

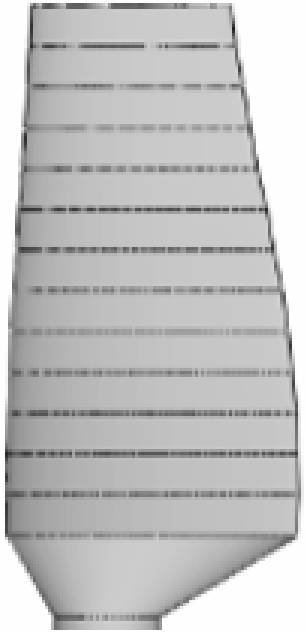
Goals	Milestones Achieved
Design a micro turbine that generates at least 10% more real power with 15% less overall mass	Max Power Output: 27-29W (11-15m/s), reduced weight of base plate by factor of 7
Decrease manufacturing lead time	3-D printing automated part of manufacturing
Improve blade durability at speeds 5-22m/s*	CF blades reduce risk of breakage at all speeds and rotational inertia, faster pitching

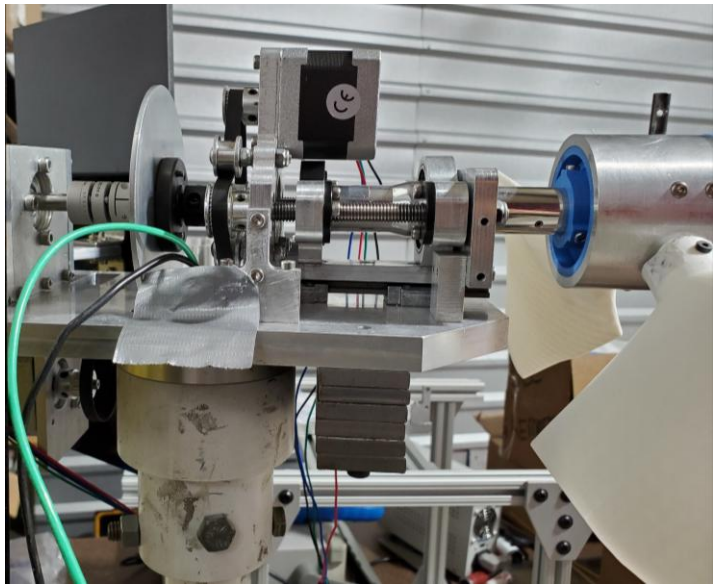
*Average wind speed on site is about 7.4 m/s (Gulf of Mexico)



Initial Configuration

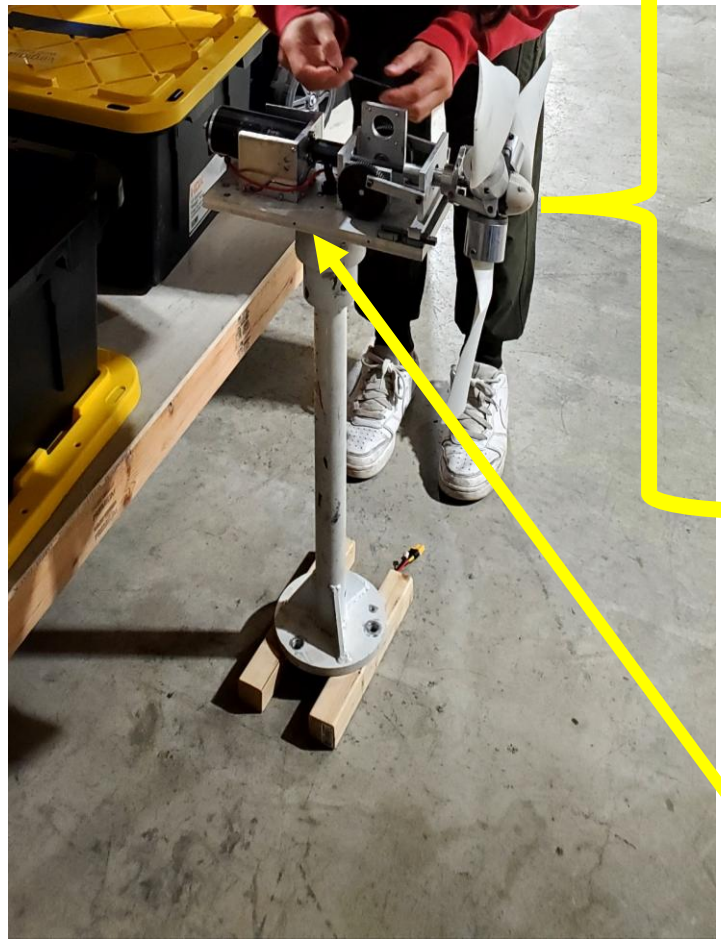
- Mainly steel (density 7.85 g/cm^3)
- Bulky with excessive rotational inertia
  - Physical brake
  - Slow pitch control
  - Overweight baseplate
- Unbalanced
- Weak blade





Final Configuration & Prototypes

- Carbon Fiber, PLA, and Steel
  - CF Density: 1.6g/cm^3
  - PLA Density: 1.43g/cm^3
- Physical break replaced by electronic power system function & pitch control
- Improved pitch control with stepper motor
- Lighter base plate allows for improved mobility
- 3k Tow 2x2 twill weave CF Blades
  - Tensile strength: 3500 MPA vs 60 MPA (PLA)
  - CF & PLA composite prototypes also tested



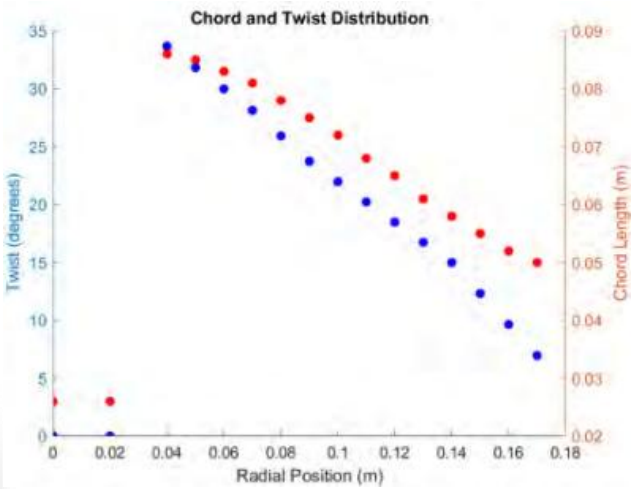
Data Analysis

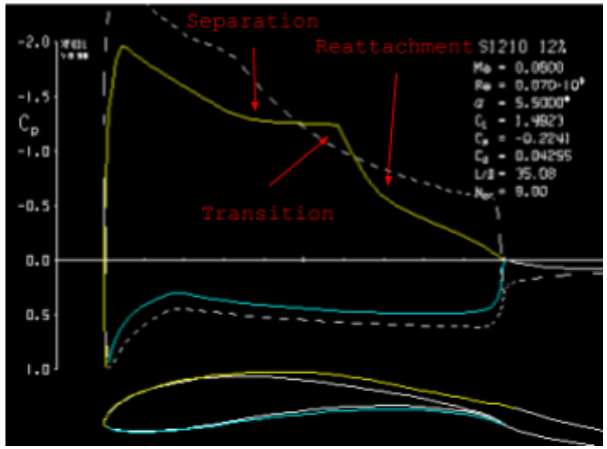
- Blade Element Momentum Theory (BEMT)
- MATLAB & Python Programs
  - Outputs optimal chord and twist parameters based on use-case (high vs low wind speed)
- Maximum Power Point Tracking (MPPT) to help match load resistance to rotor RPM and maximize power
- XFOIL
  - Simulated blade parameters (lift/drag, coef. of power (Cp), Reynold number)
- Annual Energy Production

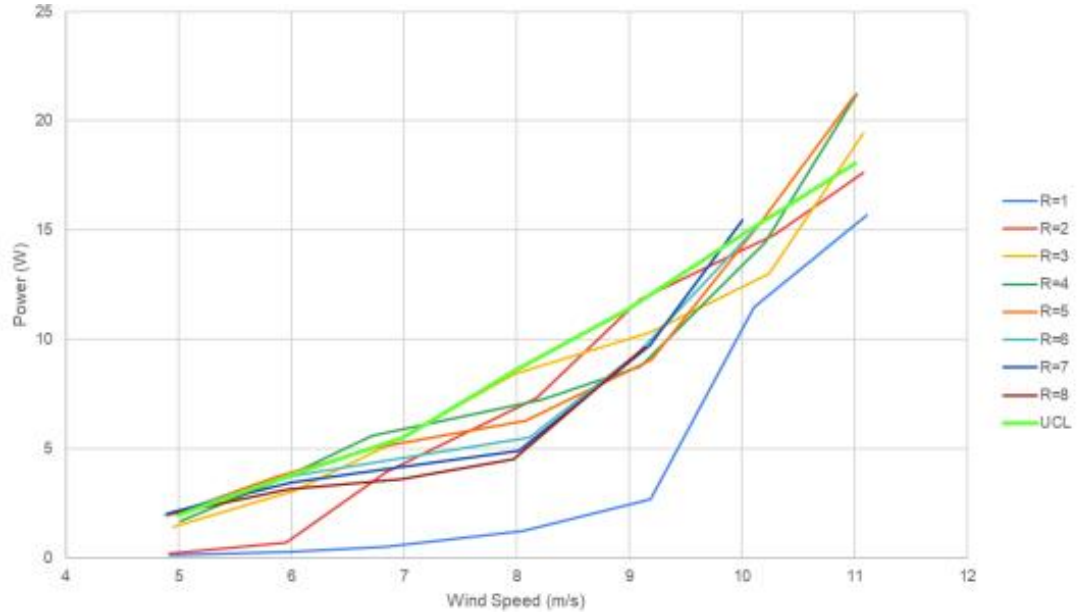
$$AEP = (Operating\ Hours\ Per\ Year) \int_0^\infty (P(V))(Probability(V))\, dV$$

- Wind speed probability

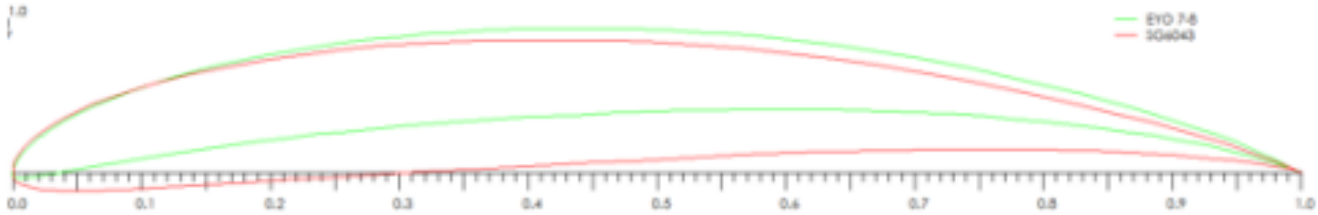
$$f(V_1 < V < V_2) = exp(-(V_1/A)^k) - exp(-(V_2/A)^k)$$



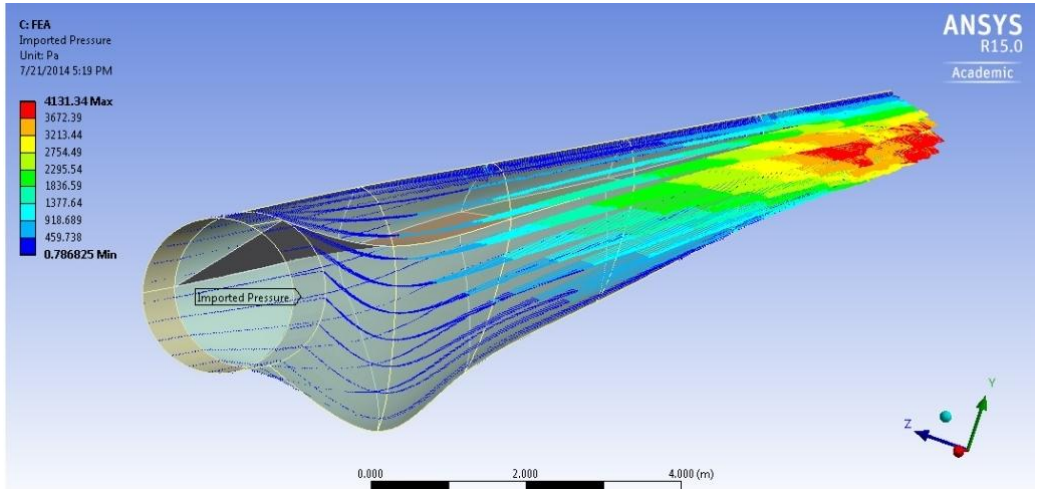




Blade Design



- Hybrid Blade Geometry:
  - Experimental EYO 7-8 (tip)
  - SG 6043 (root)
  - Transition point at 50% of radial position
- Conditions:
  - Reynolds Number: 70,000-150,000
  - Optimal Tip-Speed Ratio: 1.5
  - Best for cut-in and low speeds under 10 m/s
- Temporary Negative Mold method
  - PLA mold dissolved with acetone inside CF

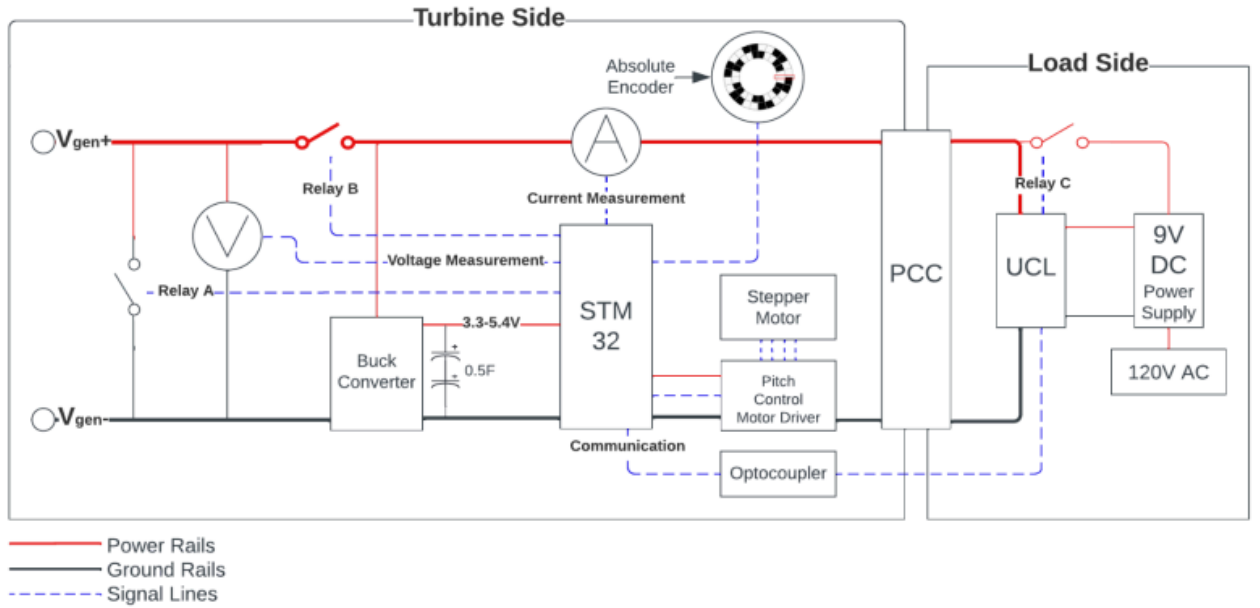


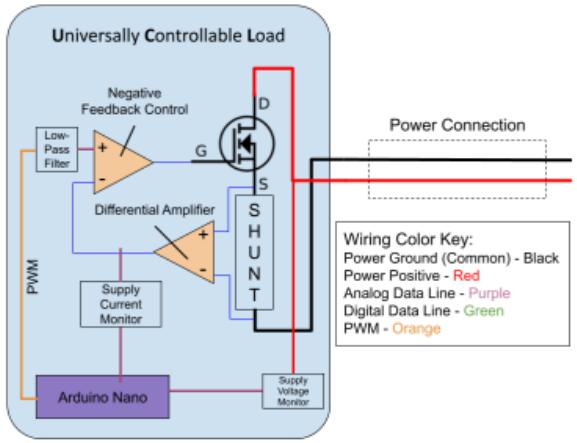
Mechanical

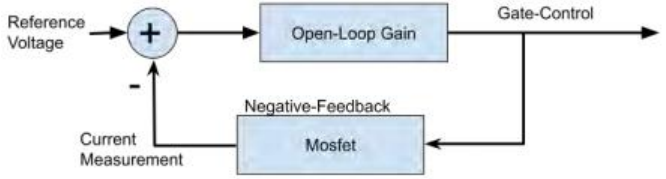
- Auto-actuating pitch control optimizes angle of attack
  - Based on resolver feedback
- Swashplate & links + stepper motor actuation for smooth motion, stability, and compactness
- CF base plate & blades lower mass, improve balance, ease yaw

Electrical

- *Universally Controllable Load*
  - Controllable load resistance
  - Closed loop Voltage regulator
  - Modes: constant current, resistance, power, voltage, MPPT
- *MPPT for max power at any wind speed*
  - Matches load (UCL) impedance with calculated optimal generator impedance
- Short circuit for braking on turbine side
- Encoder reads blade pitch

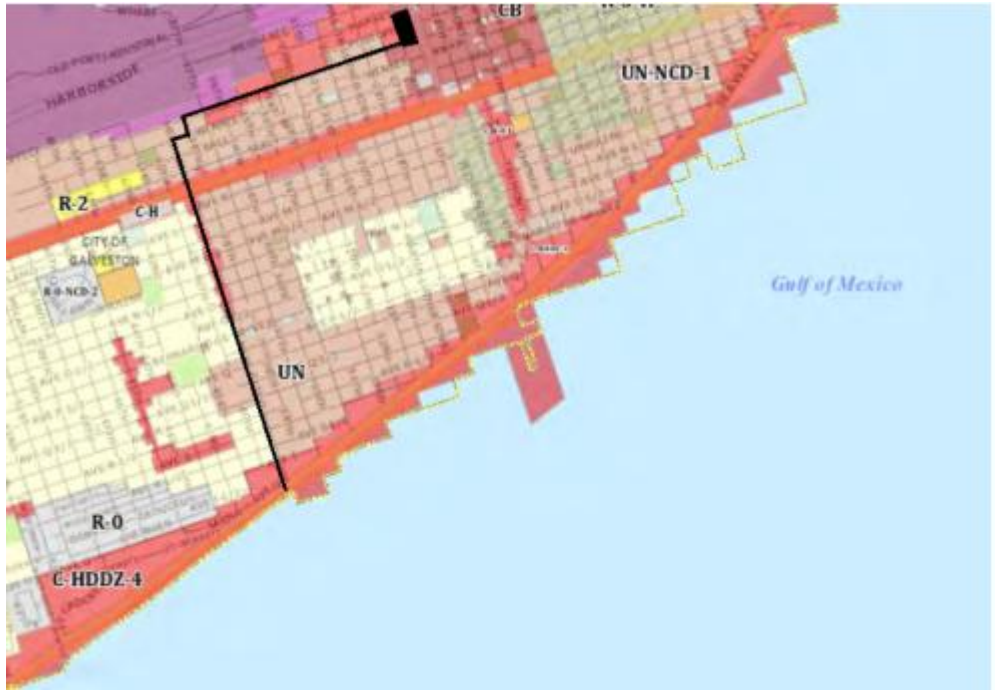


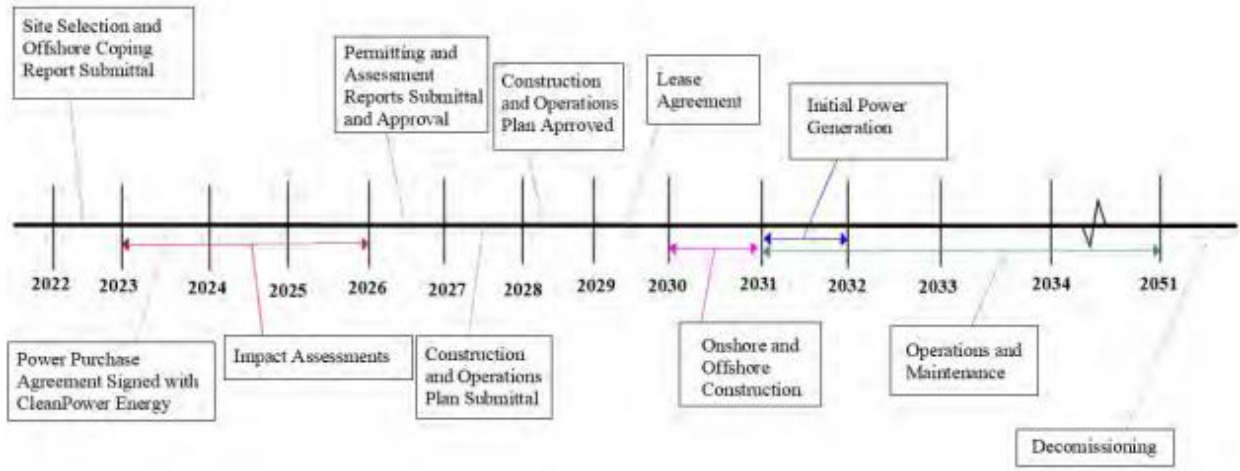




Standards

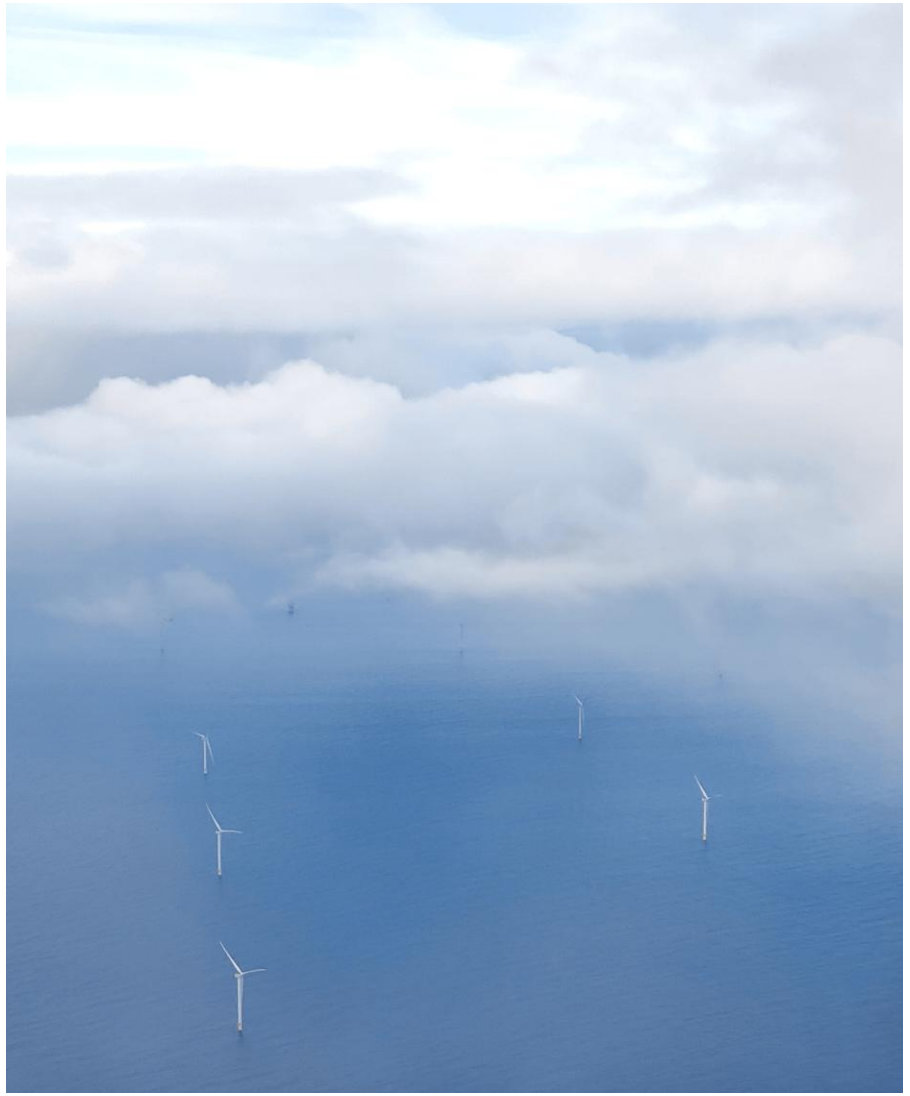
- Interconnection with CenterPoint Energy utility
  - 345-kV and 138-kV transformers and transmission lines
  - IEEE1547-2018
  - UL1741
  - NEC 705
- Site under federal jurisdiction
  - Site Assessment Plan, Facility & Design Report, Fabrication & Installation Report, Construction & Operations Plan





Further Improvement

- Heavy blade-hub coupler could be male to female connection
- More granular MPPT/pitch adjustments
- High chord reduced performance at high wind speeds
- 3-D print more system components (linkages, swashplate, etc.) to decrease manufacturing time and increase iteration
  - First 3-D printer was pitched by myself and acquired after long negotiations with team
- Further research and integration of CF/PLA composite blades
  - Possibility to be additively manufactured



Taken by me on a flight to Schipol Airport, Netherlands

Appendix

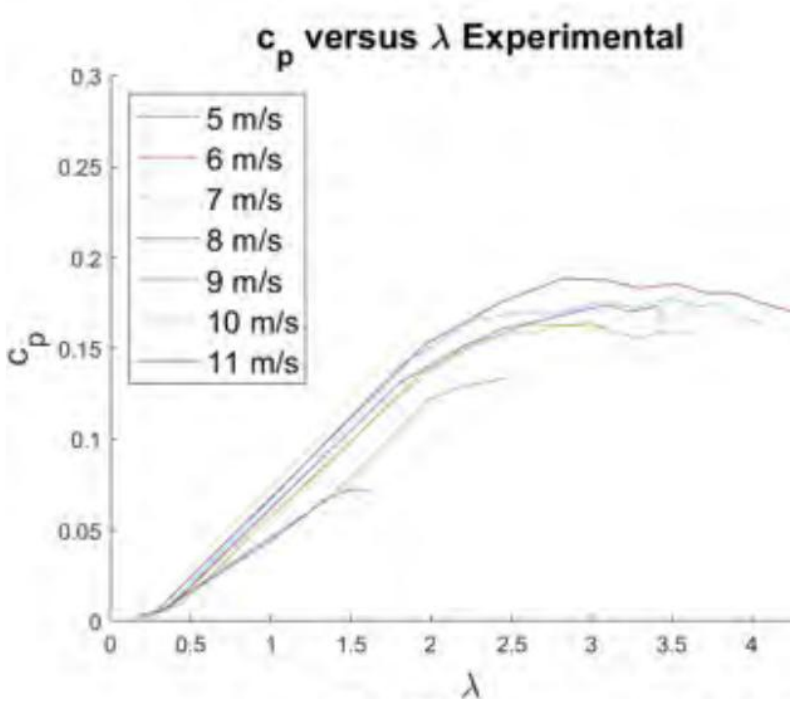
Financials

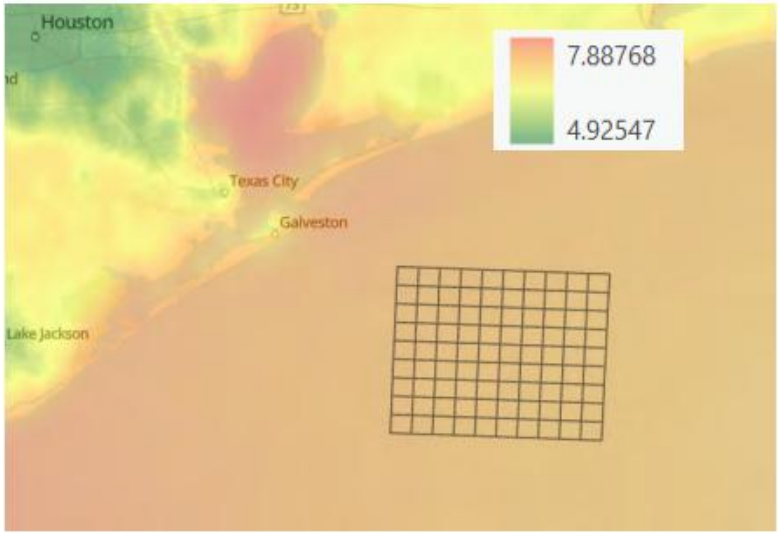
- Production life: 20 years
- Total Project Cost: $2.87 Billion
- Levelized Cost of Energy used for market research
- Power Purchase Agreement prices calculated between 9.64¢/kWh and 10.08¢/kWh
  - Avg residential cost: 12.24¢/kWh
- Annual Energy Production

$$AEP = (Operating\ Hours\ Per\ Year) \int_0^\infty (P(V))(Probability(V))\, dV$$

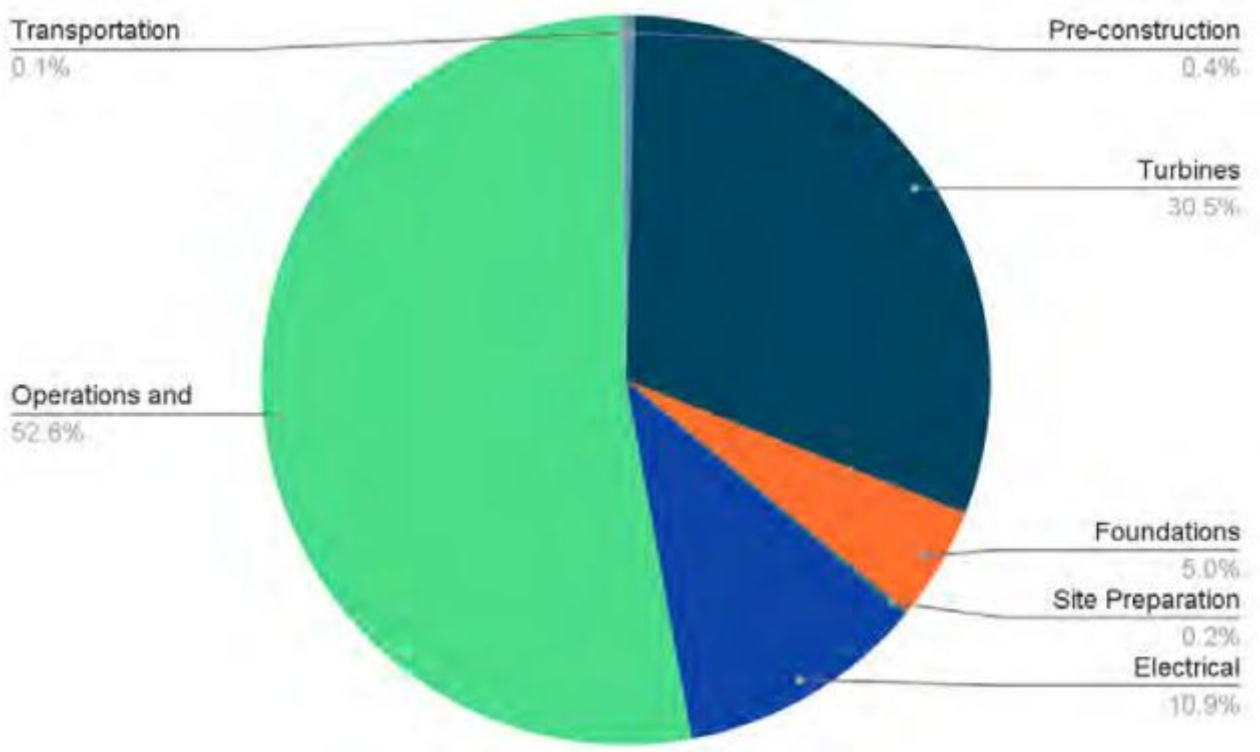
- Wind speed probability

$$f(V_1 < V < V_2) = exp(-(V_1/A)^k) - exp(-(V_2/A)^k)$$



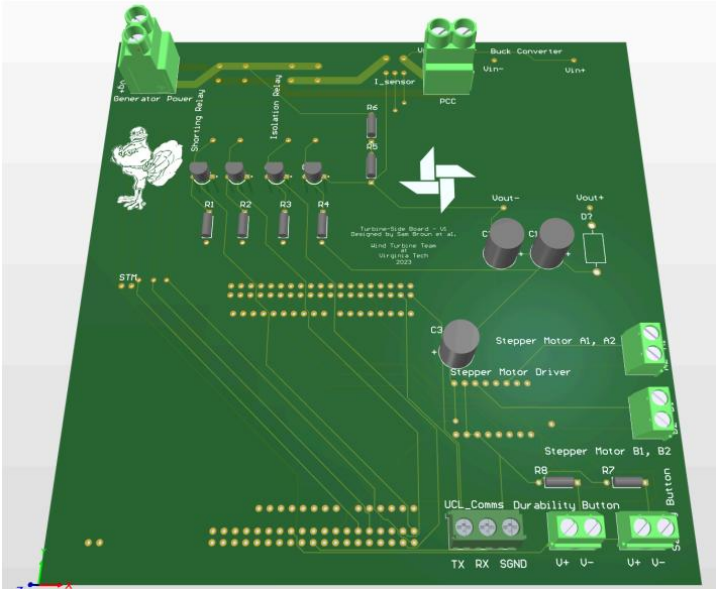


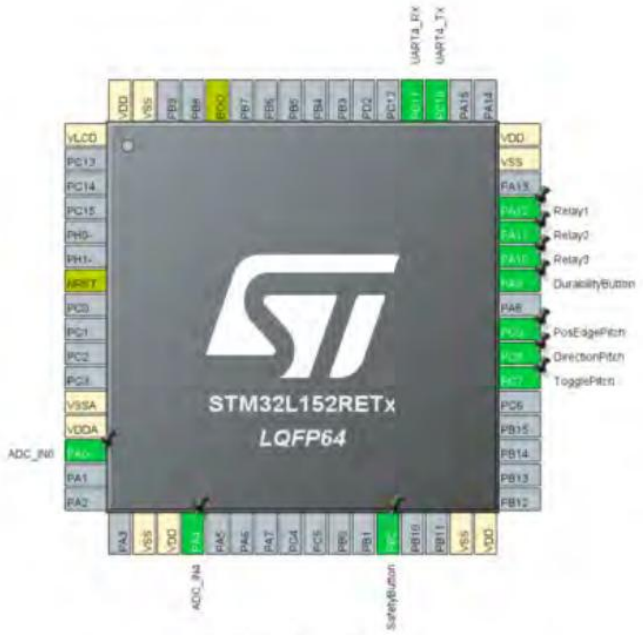
Financials


Transportation
0.1%
Pre-construction
0.4%
Turbines
30.5%
Operations and
52.6%
Foundations
5.0%
Site Preparation
0.2%
Electrical
10.9%

Electrical Components

- Maxon RE-50 brushed DC generator
- STM32 Microcontroller
  - Contains Finite State Machine
- Finite State Machine relays instruction to other systems depending on function state (Safety , Cut-In, Durability, Power)
- Perturb and Observe algorithm
  - Iteratively measures power at different resistances
  - If current W is higher than previous, resistance increases or vice-versa
- Optocoupler used for communication between UCL and STM32 to isolate turbine side from load side, preventing power flow

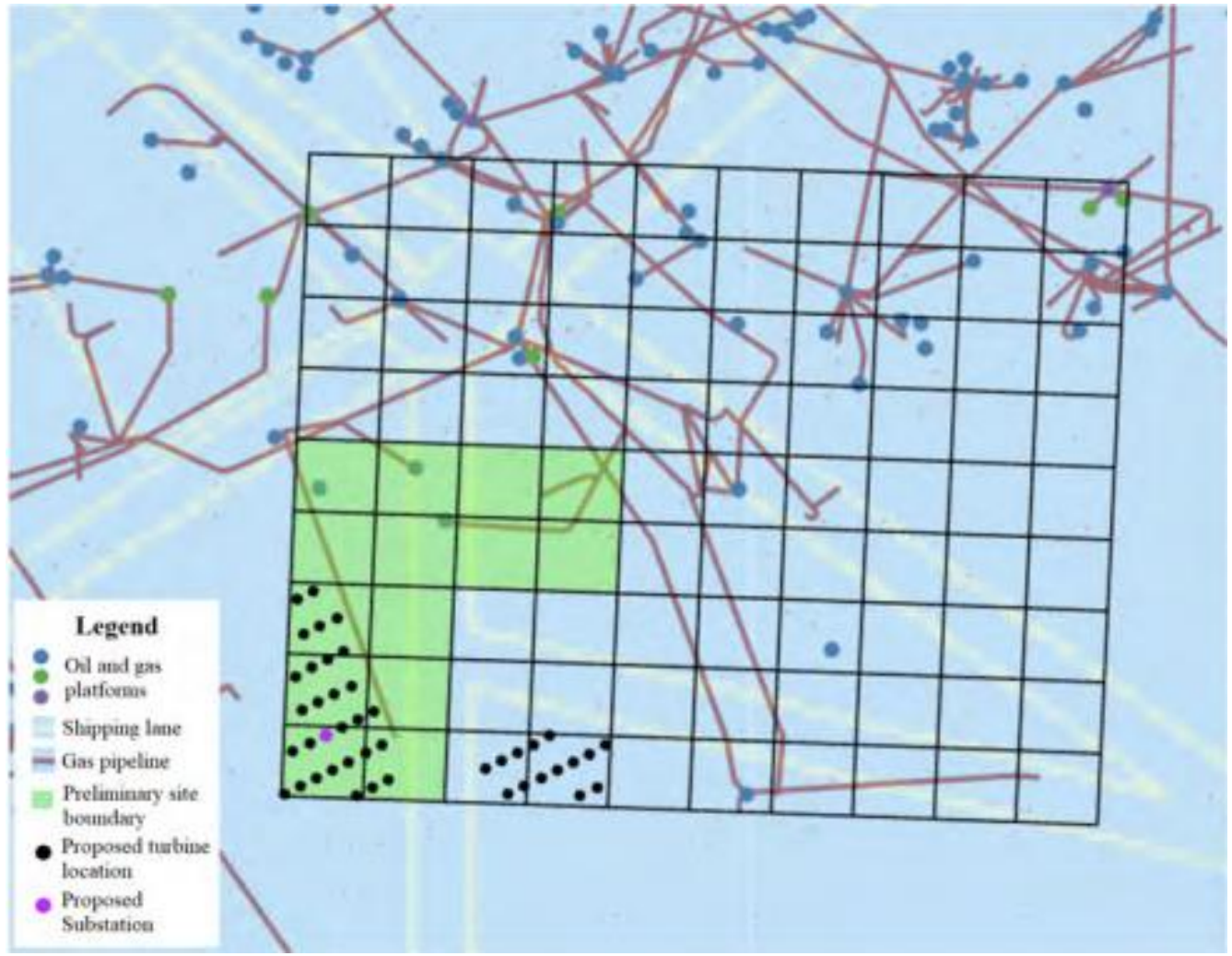


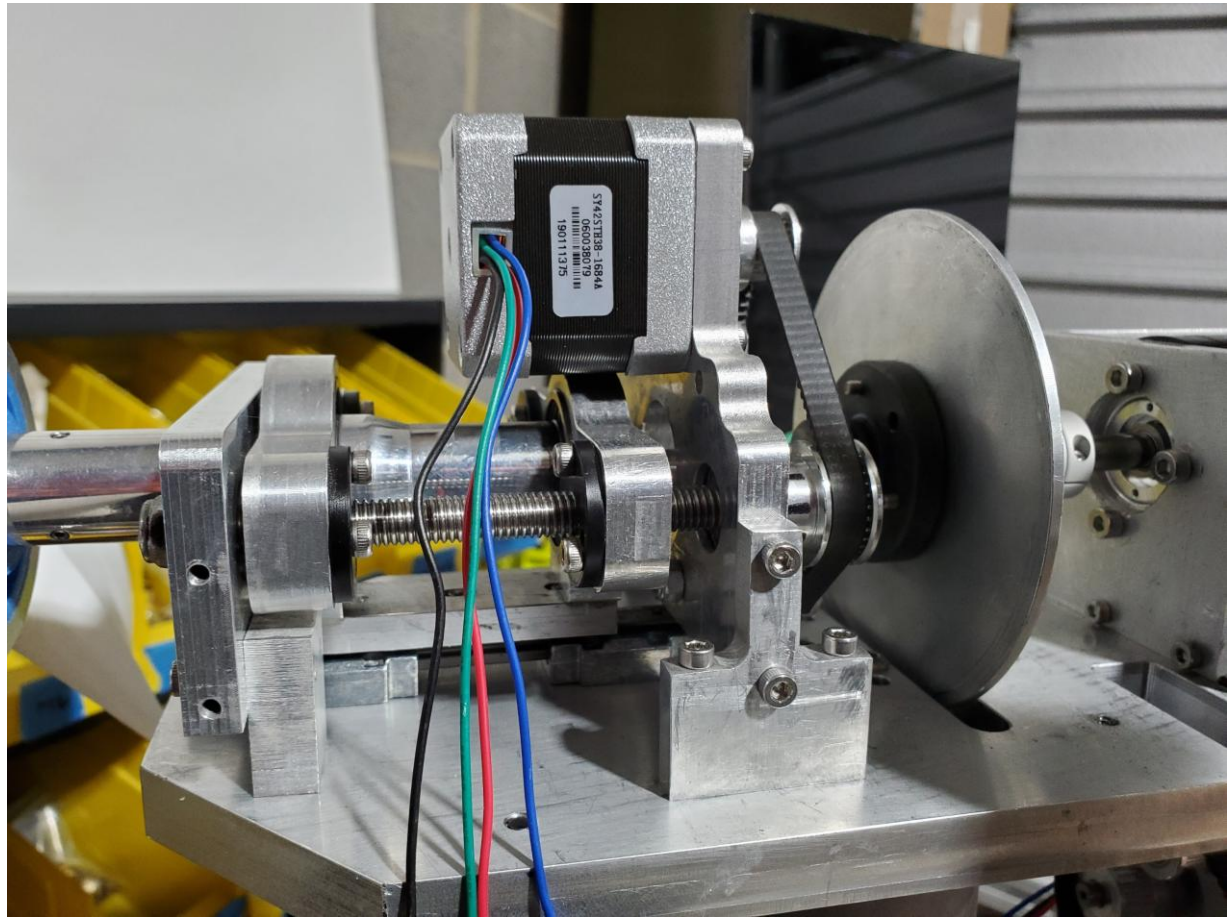


Wind Farm

- Estimated capacity factor of 42.5%
- Estimated total annual energy production of 44.7 Million kWh/turbine
- Substation was placed in the middle of site to reduce cable lengths and reduce electrical efficiency
- Connection between the offshore substation and land (55km) will require two 220kV cables (to create redundancy and avoid failures)
  - Individual turbines will be connected with 66kV wires

*EYO airfoil research


Legend
Oil and gas platforms
Shipping lane
Gas pipeline
Preliminary site boundary
Proposed turbine location
Proposed Substation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