POWER U

FOR THE FUTURE, BY THE FUTURE

Expanding college students' wind energy education and perception to prepare them for fulfilling careers in renewable energy and a more sustainable future

California State University, Chico

College of Business

College of Engineering, Computer Science, and Construction Management

For submission to Collegiate Wind Competition 2018

April 23, 2018

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The information in this business plan is also inherently forward-looking information. Among other things, the information: (1) discusses the company's future expectations, (2) contains projections of the company's future results of operations or of its financial condition, (3) states other "forward looking" information. There may be events in the future that the company cannot accurately predict or over which the company has no control, and the occurrence of such events may cause the company's actual results to differ materially from the expectations described herein.

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Executive Summary

Business Overview
PowerU is a non-profit organization dedicated to expanding college students' wind energy education and perception. We do this by providing an interactive installation in a high traffic area of college campuses with a wind turbine lab in an open space with conditions suitable to power two wind turbines, horizontal and vertical axis.

We designed the interactive installation to be a place where students can linger by having modular seating with charging stations and a live-feed camera of the wind turbines with a visual light display depicting the amount of energy produced.

Problem
College students have typically seen wind turbines driving through desolate, fenced off areas across the United States. Since students rarely get exposure to or an opportunity to interact with wind turbines, they don't consider the wind industry as a viable career opportunity. There are 59 4-year universities that have a wind energy program, which makes up for just 1.9% of all of 4-year colleges. This is especially relevant considering that the wind industry continues to grow and generated a record 6.3% of electricity in the United States. There are 14 states that generate more than 10% of their electricity from wind with states like Iowa, Kansas, Oklahoma, and South Dakota generating more than 30%.[1]

Solution
PowerU will provide the resources for colleges to expand students' wind energy education and perception to better prepare students for a fulfilling career in the wind industry. The interactive installation and wind turbine lab on college campuses will offer students the opportunity to get hands-on experience and increase knowledge of wind turbines and the wind energy industry. Students will be better prepared for fulfilling careers in the wind industry.

Target Market
Our beachhead target market is four-year colleges in the United States that are committed to a more sustainable future. Our pilot launch will be at California State University, Chico (Chico State) in 2019.

Table 1: Deployment Snapshot

Year 1	Year 2	Year 3
Pilot at Chico State	Expand to 2 additional campuses	Expand to 4 additional campuses

Business Model
PowerU will partner with corporate sponsors and our strategic partners to incorporate our interactive installation and wind turbine lab on college campuses.

Table 2: Financial Snapshot

	Year 1	Year 2	Year 3	Year 4
Sales	$125,000	$255,000	$520,200	$1,061,208
COGS	$58,825	$119,415	$242,412	$492,096

Gross Margin	$46,025	$95,286	$197,190	$407,915
Total Operating Exp.	$193,000	$233,000	$248,000	$263,000
Net Income	($146,975)	($137,714)	($50,810)	$144,915

Product

Figure 1: Modular Seating and Charging Unit

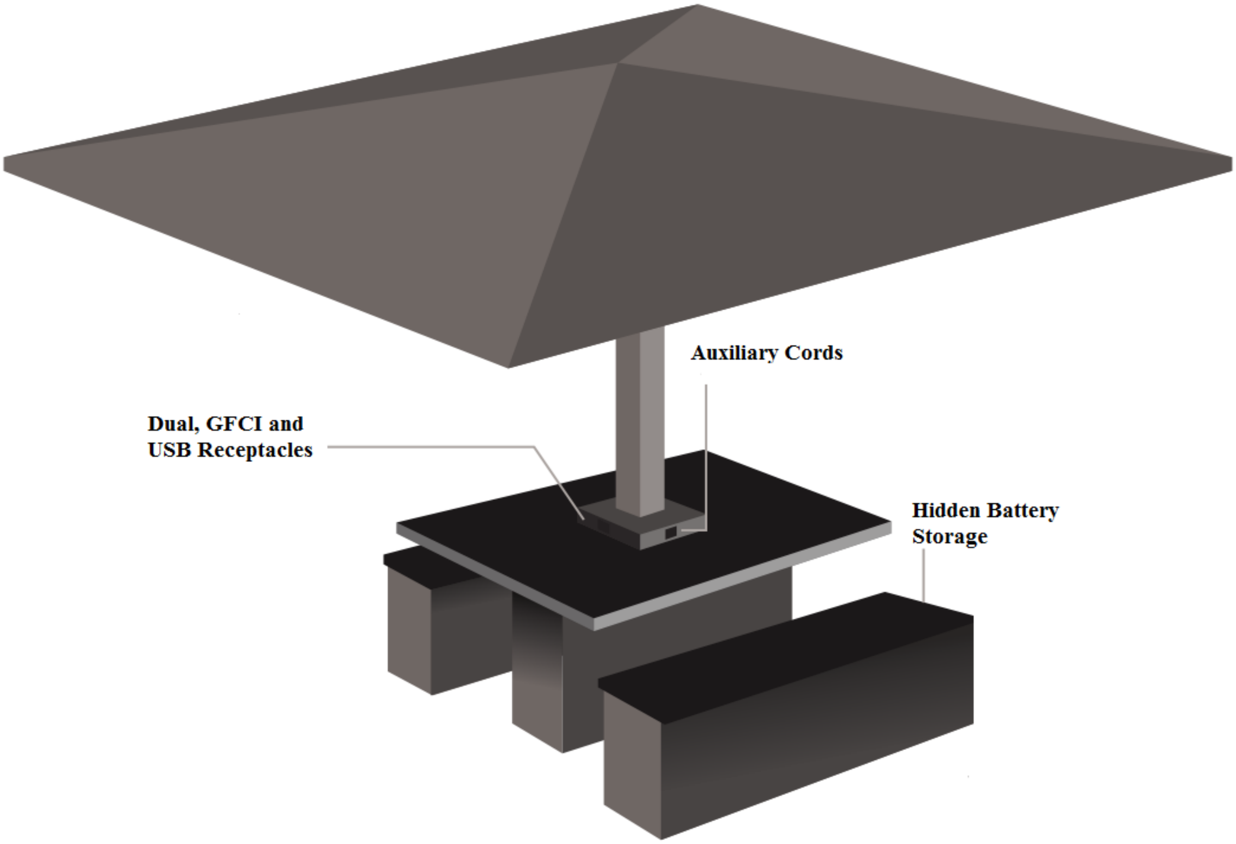


Figure 2: Interactive Display

Business Plan

Business Overview
PowerU is non-profit organization dedicated to:

- Raising college students' **awareness of wind energy**
- Creating a young**, qualified workforce** for wind energy corporations
- **Connecting students** interested in wind energy to corporations seeking to hire young professionals
- Providing universities with an **interactive installations** demonstrating the power of wind
- **Supplying curriculum** to faculty interested in teaching wind energy related concepts

PowerU was created by an interdisciplinary group of students passionate about wind energy and believing in the industry's growth opportunities.

By partnering with corporate sponsors, PowerU, is able to provide the interactive wind energy displays to universities for free.

We supply the materials and electronics as well as design specifications and advice on permitting procedures. Through a partnership with Kid Wind, we also work with faculty members on ways to incorporate the installation as part of their curriculum.

We will consider all university applications. However, applications that will be given priority should include:

- Two faculty member leads from two different colleges or schools (i.e. business, engineering, arts & sciences).
- Two student organization champions related to renewable energy or sustainability
- A letter of support by the university president and provost

Products and Services
PowerU provides all of the materials, electronics, design specifications, and advice on permitting procedures necessary for an interactive installation and wind turbine lab on college campuses.

Interactive Installation

The interactive installation would be located in a high traffic area of college campuses where it would be seen frequently. When designing the installation, we were determined to create a space where students would linger by having modular seating with charging stations. Outdoor seating with access to an outlet to charge devices like cell phones, laptops, and tablets are at a premium on campuses.

The monitor with a live-feed camera of the wind turbines, a visual light display depicting the amount of energy produced, and an overview of the basics of how wind turbines work would facilitate and spark student interest.

Wind Turbine Lab

The wind turbine lab would be located in an open space with conditions suitable to power two wind turbines, horizontal and vertical axis, that are approximately 10 kW. The opportunity for students to have meaningful hands on experience was a critical factor when determining the size and types of wind turbines.

We chose 10 kW fully-functional wind turbines connected to the grid with the ability to operate in islanded mode. The blades of the wind turbines would be interchangeable and the pitch would be adjustable giving students an opportunity to experiment with adjusting the efficiency of the wind turbine.

Choosing a safe location for the wind turbines and ensuring the turbines are up to code and inspected by all appropriate parties is a priority. All necessary safety measures and precautions will be taken and we will coordinate with OSHA, Facilities Management, and the State Fire Marshall. In addition, an emergency plan and detailed maintenance schedule will be provided for each installation.

Wind Power Lab Curriculum

Quantify wind resources available at site

- Collect wind speed and direction hourly
- Plot histogram of hourly wind speeds (accumulate into a year's worth of data)
- Display the results in a Weibull Distribution (frequency of occurrence (%) versus wind speed)
- Determine most frequent wind speed
- Determine total annual energy produced
- Estimate capacity factor

Plot wind turbine power curve

- Measure electrical power produced
- Estimate mechanical power from electrical motor specifications
- Plot mechanical power versus wind speed
- Identify cut in wind speed, rated wind speed, and rated power

Estimate wind turbine efficiency

- For a fixed pitch, measure rotor RPM and mechanical power for a specified wind speed at various load settings
- Calculate Power Coefficient (Cp, ratio of mechanical power to total power available in wind) and Tip Speed Ratio (TSR, ratio of the speed of the blades at the tip and wind speed) at each load setting
- Plot Cp versus TSR for one wind speed and all load settings
- Overlay Cp versus TSR for multiple wind speeds and the same load settings

- Identify the wind speed and load setting that produces the highest Cp. Identify the TSR for the highest Cp.

Target Market

Our beachhead target market is four-year colleges in the United States who are committed to a more sustainable future. Because PowerU is determined to continue sustainability and diversity efforts, colleges with two faculty member leads from two different colleges or schools (i.e. business, engineering, arts & sciences), two student organization champions related to renewable energy or sustainability will be given priority. After we have successfully launched at our first seven four-year colleges, we will pursue two-year colleges and technical schools. We are committed to ensuring that there is interdisciplinary collaboration and participation in PowerU programs because the future of the renewable energy is dependent on innovation.

The beta launch will be at California State University, Chico (Chico State) in 2019. Chico State is a strong entry point for us because the university is committed to sustainability and diversity, these goals and values are supported by both students and administration. This commitment to sustainability is best demonstrated by the elimination of single-use plastic straws on campus. The #strawlessatchicostate is headed by the Associated Students Sustainability Program, which is the student government body at Chico State that runs all of the dining programs and cafes on campus.

Strategic Partners

This is the first group of partners that we have reached out to and are anticipating a positive response for partnership to bring PowerU to colleges in the United States.

Kidwind

KidWind has been helping students and teachers explore wind energy for nearly 20 years. KidWind champions a hands-on and interdisciplinary wind energy curriculum that prepares students for careers in science, technology, and engineering. We will partner with KidWind to open up our facilities to host KidWind Challenges and neighboring schools. This will be an excellent opportunity for college students to participate in activities that benefit the community and strengthen their wind energy knowledge.[2]

Women of Renewable Industries and Sustainable Energy (WRISE)

WRISE was founded in 2005 and has been working to change the future of our energy future through the actions of women. WRISE advocates for the recruitment and advancement of women in the energy industry. WRISE will be a beneficial partner for us because by utilizing their coaching and mentoring program for young women, together we can insure and more diverse and empowered workforce.[3]

The Institute for Sustainable Development

The Institute for Sustainable Development has hosted the This Way to Sustainability Conference at California State University, Chico for the last thirteen years. Every year there is a difference theme that addresses a wide array of topics and explores collaborative and interdisciplinary solutions to unsustainable practices. This conference draw a wide audience of students, faculty, community members, and sustainability focuses leaders. This is the largest student run and organized sustainability conference of its kind in North America and will be an important partner us because they already have a passionate student and community following. [4]

Society of Women Engineers (SWE)

SWE is a student society for women engineers that was founded in 1950. SWE is passionate about helping women achieve full potential in their careers as engineers and leaders, expanding the image of the engineering profession as a positive force in improving the quality of life, and demonstrating the value of diversity. SWE is a powerful partner for us since they are already widely established on college campuses and its members are students we want involved in PowerU programs.[5]

Business Model

PowerU partners with corporate sponsors to fund the installation of our interactive installation and wind turbine lab on college campuses. While the cost to implement our installation on each campus would vary, below is an estimate of costs to install at Chico State.

Table 3: Budget Snapshot

Materials	Electronics	Installation	Total
$28,666	**$2,909**	**$25,250**	**$56,825**

Corporate sponsorship packages begin at $5,000. Benefits of being a corporation sponsor include:

- Exposure opportunities include a company-branded display screen, plaque installation on table, and branding of umbrella underside
- Select judging invitations
- Dedicated faculty contact person
- VIP meet and greet with top students
- Inclusion on all communication and marketing materials

Board of Directors

PJ Shepard, Board Chair

PJ Shepard has over 20 years of experience in the medical device industry from the university laboratory setting to project management and product marketing. She has participated in writing grant applications for electric vehicle charging systems as well as geothermal, solar and airborne wind energy projects. On behalf of the Airborne Wind Energy Consortium she continues to share promotion efforts for this new renewable energy sector. She has worked in the public, private and nonprofit sectors focused on human and animal health and quality of life. Ms. Shepard holds a B.S. in Plant Science from UC Davis with Highest Honors, and an A.S. in Electronic Engineering Technology from Heald Engineering College, San Francisco. PJ is highly committed to energy innovation, improving health care related outcomes and the health of our planet pertaining to water, food and energy supplies.

Dr. Colleen Robb Faculty: Entrepreneurship

Dr. Colleen Robb is an internationally recognized researcher in the area of strategy and social entrepreneurship, specifically examining how social ventures can maintain advantage in the marketplace. Dr. Robb currently serves as an assistant professor of entrepreneurship for California State University, Chico and is the Director for the Center of Entrepreneurship. She has over 15 years of experience in the nonprofit sector in various roles for organizations such as MedShare International, the University of Cincinnati, and Best Buddies International. Dr. Robb holds a B.F.A. and M.B.A. from Florida International University and a Doctorate of Economics and Business Administration from Abo Akademi University in Finland.

Dr. David Alexander Faculty: Engineering
Dr. Alexander has 10 years of industry work experience most of which as CEO of IVUS Energy Innovations – a technology start-up company that he and three partners formed around unique fast changing technology. As CEO, he raised over $2 million in equity financing, secured a worldwide license agreement, and managed the commercialization and launch of the industry's first 90-second rechargeable flashlight. In addition he is co-inventor on four U.S. patents and has presented numerous times at advanced energy technology conferences in the areas of business and technology development.

Chris Purvis
Chris Purvis works as the Chief Software Architect for Dreamscape Immersive and he is an alumni of California State University - Chico. His job is to lead the software development for Dreamscape Immersive's location-based immersive, theatrical, social VR experiences. He is also in charge of their content development and location operations systems.

Pablo Silveira
Pablo Silveira works as a GIF analyst for EDF renewable energy and is a California State University - Chico alumni. He primarily works on solar and wind energy projects throughout the state of California; but he has worked in other states before. His main focus on his projects are cartography for project development, GIS data management, project preliminary design and project permitting.

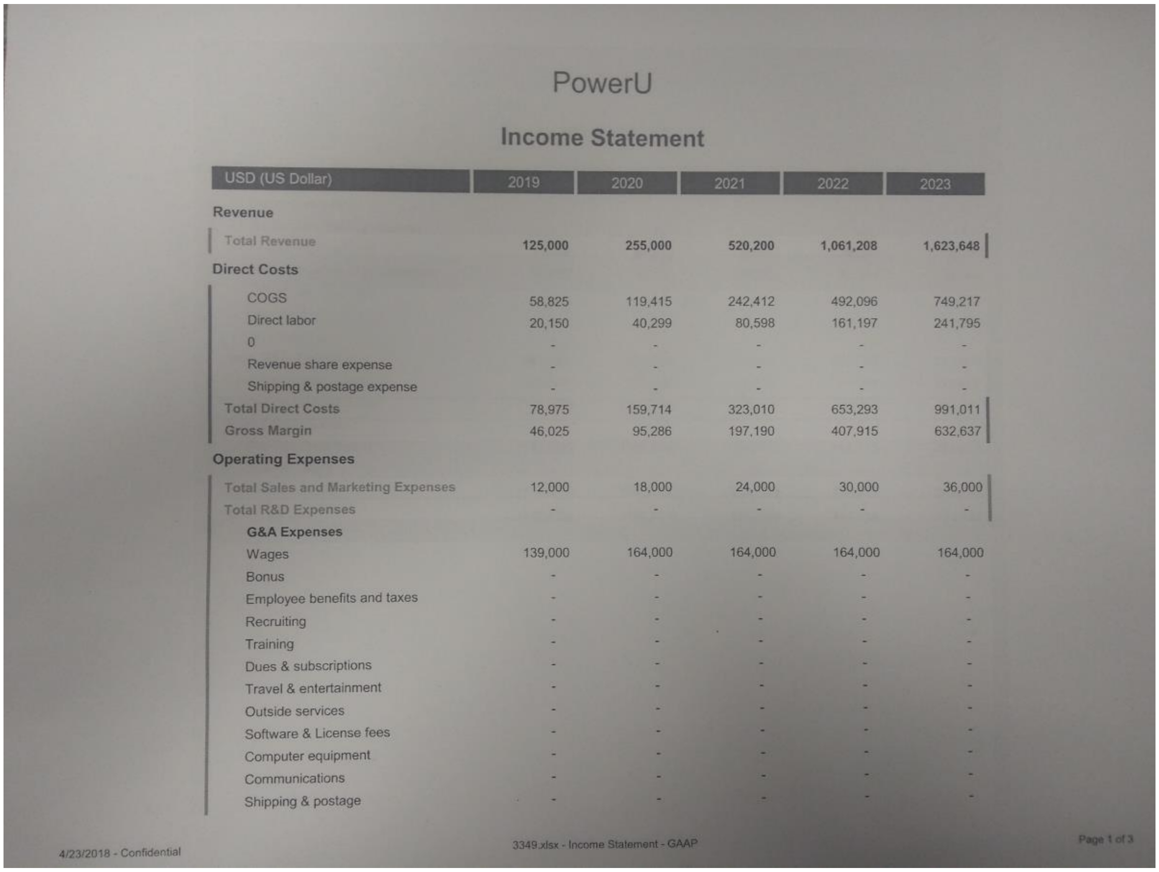
Angela Cassler
In 2006 Angela Cassler began lecturing at California State University Chico. Presently, Angela is highly involved in University organizations such as, Sustainable Consultation of Office Practices (SCOOP) and social fraternities such as, Phi Chi Theta Delta Chi chapter, a professional business and economic fraternity. Angela also is a counselor for the small Business Development Center for Chico State. Since 2012, Angela has held position of CEO/President of the Sustainability Management Association and founded Sustainability Management Consulting in 2010.

Management Team
Paige McMath-Jue, CEO, University Relations Manager
Ty Hartl, Vice President, Corporate Relations
Jack Nevin, Vice President, Operations
Aaron Lee, Vice President, Engineering

Deployment Team
Olybert Velasco, John Walters, Sang-Mo Ryu, Trenton Waterman, Andrew King, Dylan Velazquez, Spencer Short, and Rhys "Rosetta" Zanella.

Financials

Figure 3: Income Statement



PowerU

Income Statement

USD (US Dollar)	2019	2020	2021	2022	2023
Revenue					
Total Revenue	**125,000**	**255,000**	**520,200**	**1,061,208**	**1,623,648**
Direct Costs					
COGS	58,825	119,415	242,412	492,096	749,217
Direct labor	20,150	40,299	80,598	161,197	241,795
0	-	-	-	-	-
Revenue share expense	-	-	-	-	-
Shipping & postage expense	-	-	-	-	-
Total Direct Costs	78,975	159,714	323,010	653,293	991,011
Gross Margin	46,025	95,286	197,190	407,915	632,637
Operating Expenses					
Total Sales and Marketing Expenses	12,000	18,000	24,000	30,000	36,000
Total R&D Expenses	-	-	-	-	-
G&A Expenses					
Wages	139,000	164,000	164,000	164,000	164,000
Bonus	-	-	-	-	-
Employee benefits and taxes	-	-	-	-	-
Recruiting	-	-	-	-	-
Training	-	-	-	-	-
Dues & subscriptions	-	-	-	-	-
Travel & entertainment	-	-	-	-	-
Outside services	-	-	-	-	-
Software & License fees	-	-	-	-	-
Computer equipment	-	-	-	-	-
Communications	-	-	-	-	-
Shipping & postage	-	-	-	-	-

4/23/2018 - Confidential

3349.xlsx - Income Statement - GAAP

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PowerU

Income Statement

USD (US Dollar)	2019	2020	2021	2022	2023
Bad debt expense	-	-	-	-	-
Payment processing expense	-	-	-	-	-
Occupancy Expenses	30,000	33,000	36,000	39,000	42,000
Professional Services Expenses	12,000	18,000	24,000	30,000	36,000
Other G&A Expenses	-	-	-	-	-
Depreciation	-	-	-	-	-
Amortization	-	-	-	-	-
Total G&A Expenses	181,000	215,000	224,000	233,000	242,000
Total Operating Expenses	193,000	233,000	248,000	263,000	278,000
Operating Income (Loss)	(146,975)	(137,714)	(50,810)	144,915	354,637
Total Other Income	-	-	-	-	-
Pre-Tax Profit (Loss)	(146,975)	(137,714)	(50,810)	144,915	354,637
Income Taxes	-	-	-	-	-
Net Income (Loss)	**(146,975)**	**(137,714)**	**(50,810)**	**144,915**	**354,637**
EBITDA (Loss)	**(146,975)**	**(137,714)**	**(50,810)**	**144,915**	**354,637**

3349.xlsx - Income Statement - GAAP

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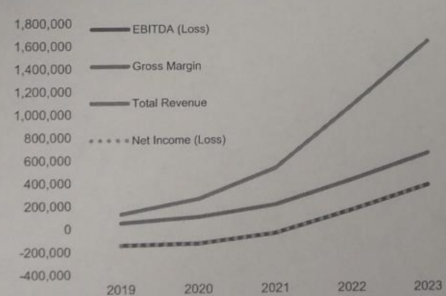
PowerU

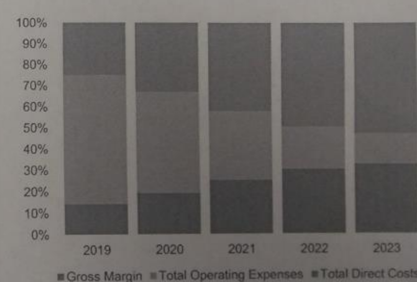
Income Statement

USD (US Dollar)	2019	2020	2021	2022	2023
Total Revenue	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**
Total Direct Costs	63.2%	62.6%	62.1%	61.6%	61.0%
Gross Margin	**36.8%**	**37.4%**	**37.9%**	**38.4%**	**39.0%**
Total Sales and Marketing Expenses	9.6%	7.1%	4.6%	2.8%	2.2%
Total R&D Expenses	0.0%	0.0%	0.0%	0.0%	0.0%
Total G&A Expenses	144.8%	84.3%	43.1%	22.0%	14.9%
Total Operating Expenses	154.4%	91.4%	47.7%	24.8%	17.1%
Operating Income (Loss)	-117.6%	-54.0%	-9.8%	13.7%	21.8%
Total Other Income	0.0%	0.0%	0.0%	0.0%	0.0%
Income Taxes	0.0%	0.0%	0.0%	0.0%	0.0%
Net Income (Loss)	**-117.6%**	**-54.0%**	**-9.8%**	**13.7%**	**21.8%**
EBITDA (Loss)	**-117.6%**	**-54.0%**	**-9.8%**	**13.7%**	**21.8%**

Revenue, Margin, and Earnings Growth



P&L Expense and Margin Mix Analysis



Technical Report

Design Objective

The purpose of PowerU's wind turbine is to provide students of many levels an opportunity of a deeper learning experience about wind turbines and the wind industry. The goal is to inform students about this renewable energy and increase awareness of wind as a clean, efficient, and viable option. The following objectives were identified and used to drive the design of PowerU's wind turbine:

- Interchangeability of parts
- Flexibility of parts and operating modes
- Reliability of performance and data
- Allow students of all backgrounds to dream of new and creative applications in the wind industry

The blades, tail, and motor mounts were designed to be easily interchangeable allowing students to study multiple performance aspects and airfoil geometries. A sliding yoke mechanism enables pitch adjustments to be made manually or automatically. Thus allowing students to study aerodynamic effects under various wind and load conditions such as: low cut-in wind speed, stall, lift, and drag.

The variable pitch system will demonstrate how improvements in efficiency can be made with simple adjustments to the blade pitch at different wind speeds. In addition, the pitch system allows the user to input an open, or closed, loop Proportional, Integral, Derivative, (PID) system to seek peak generator efficiency.

The relatively simple passive yaw system allows for interchangeability of different tail geometries. In addition, it provides an easy to understand visual response to changing wind directions while requiring zero energy from the generator to operate. The charging station and wind turbine installations provide opportunities for students to see wind turbines in action as well as interact with a real-time display of performance and efficiency.

Data is collected using an Arduino microcontroller and solid state sensors providing reliable and accurate data collection and analysis. The regulated output of the turbine will provide constant voltage output to an energy storage system. Students can sit at a PowerU charging station and power up their electronics, learn about wind, and hang out.

Market Turbine

PowerU provides college students with wind energy education and an opportunity to create a positive understanding of the wind industry. To achieve this goal, PowerU will set up an interactive installation in a high traffic area on college campuses. This interactive installation will have modular seating and charging stations for basic electronics; for example, phones, laptops, etc. A live-feed camera of the wind turbines with a visual display depicting the amount of energy produced will provide real time data of the turbine's performance.

This interchangeability of the turbine allows students to design their own blade and tail geometries. This will further their understanding of how different geometries can affect the generator output to mechanical input ratio. The overall goal is to create an interactive program where students can have hands-on experience with wind energy.'

PowerU will help set up a wind turbine lab that give students an opportunity to understand both the various forms of turbines. The main focus, however, will be horizontal axis and vertical axis turbines.

This lab will be melded with the curriculum is such a way that other engineering concepts, such as dynamics and control systems, are taken into account. The goal here is to create a course/lab that utilizes a student's engineering background to portray various aspects of the wind turbines design choices.

Static Analysis

A three-blade design provides the necessary torque for the generator at the rated wind speeds, yet has reduced drag forces that negatively impact the shaft speed. In addition, two blades or less produce chattering and dynamic forces that result in high blade stresses. With a three blade design the forces are counterbalanced and stresses are minimized.

Airfoils were selected from the Airfoiltools.com database according to the expected Reynold's number (50,000-100,000) under laminar airflow test conditions and maximum C_L/C_D (lift to drag ratio). This was also selected via the required torque and expected TSR (tip-speed ratio) for the generator. TSR is ratio of the wind speed at the tip of the blades vs the wind speed normal to them.

The blades were designed using the simulation program Q-Blade. The airfoils were analyzed and their effectiveness simulated through a range of AoA (angles of attack). Several crucial factors that were considered include: airfoil thickness, the drop severity of C_L/C_D ratio vs AoA, and maximum C_L/C_D ratio. Blades that are too thin would flex in the wind, causing erratic wind flow and torque. This would make it virtually impossible to consistently control the pitch.

The drop severity of C_L/C_D ratio vs AoA was analyzed in order to control the pitch. A more severe drop meant a finer-tuned pitch control to attain the required behavior. Lastly, the maximum C_L/C_D, which is located at the optimal AoA, dictates the maximum amount of lift, and thus torque generated from airflow.

Several of the blades that were analyzed included: S802, NACA 2418, and E63. The design with the highest C_P (coefficient of performance) was the NACA 4415, pictured in Figure (1). This airfoil has the smoothest power curve out of the batch due to its low C_L/C_D drop severity. With its low relative drop in C_L/C_D ratio, the pitch, and subsequent generator performance, is easier to control.

Once the airfoil was selected, the rotor blade was created via Q-Blade in order to optimize the angle of twist and chord length. Q-Blade was also used to model power and torque output at various wind speeds

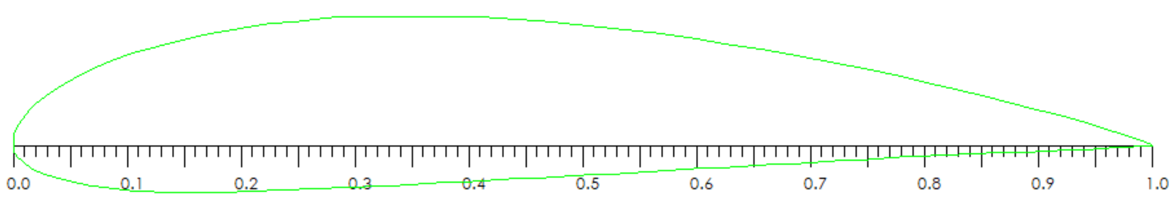


Figure 1: NACA 4415 (Cord line measurements are in percent of total cord length)

and RPM increments. The blade model was then recreated in Solidworks and features were added to provide mounting points to the sliding yoke. The blades were 3D printed out of PLA.

The TSR was selected based upon research of commercial wind turbines. The ideal TSR is limited by the geometry of the blade and the additional stresses placed at the tips. With a design wind speed of 7 m/s and expected RPM of 2000, the TSR was used to optimize the angle of twist and chord length. Figure (2) shows the C_P vs TSR with the blade optimized for a TSR of 5 based on Q-Blade analysis. The generator did play a factor into the design of the blades since the team focused on performance/RPM rather than torque produced. The higher the RPMs meant more power the generator would produce while still creating enough torque to have a low cut-in wind speed.

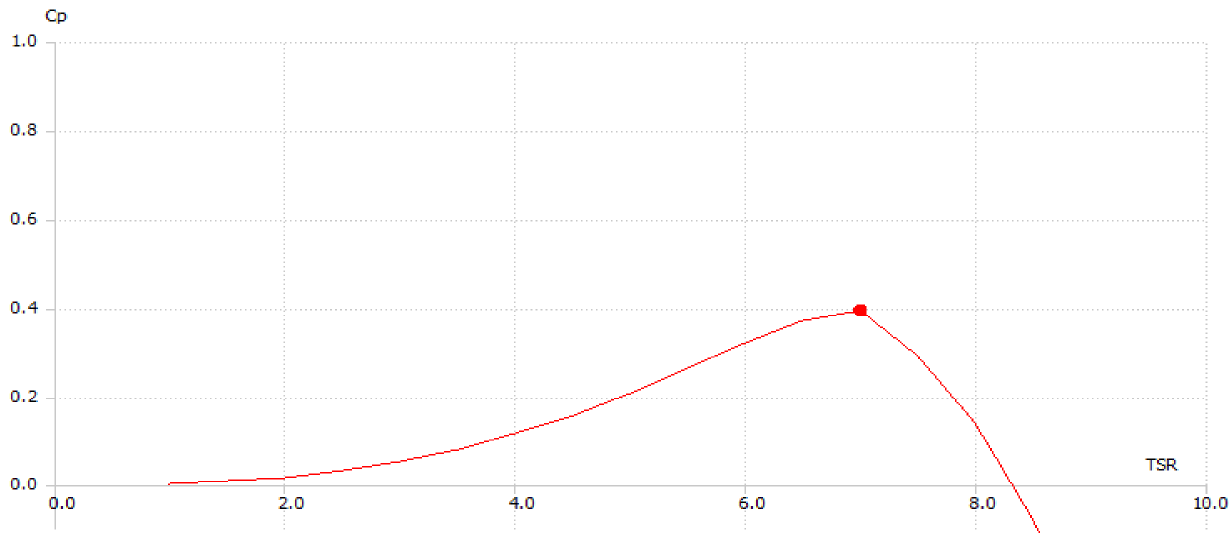


Figure 2: Cp Vs TSR

Q-Blade was used to develop the blade profile and characteristics shown optimized at the chosen TSR. Figure (3), shows the shape of the blade after inputting TSR, Reynold's number and angle of twist.

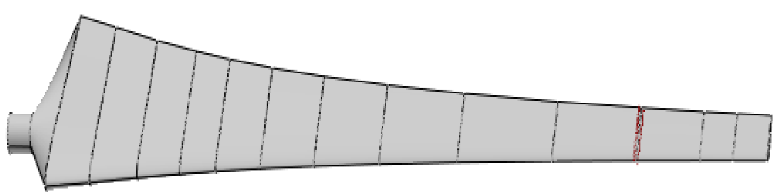


Figure 3: NACA 4415 Blade

Pitch
A sliding yoke mechanism, Figure (4), is used in order to maintain a desired power output by adjusting the pitch of the blade when wind speeds are too high. Reducing the pitch lowers lift force. This allows the wind turbine to maintain a constant RPM at increased wind speeds and maintain a steady power output from the generator. A 20 threads-per-inch lead screw is used to adjust the sliding yoke and is used due to level of accuracy it attains. The lead screw is driven by a continuous servo motor controlled by an Arduino Nano. The Arduino gathers RPM data from a Hall Effect sensor, which will sets the pitch for a steady power output. The change in pitch is monitored via a linear potentiometer connected to the lead screw. Values (0-1023) are read by the Arduino and will correlate to the pitch. By having a variable pitch system students will be able to test the different pitch angles and see the different efficiencies with each blade design.

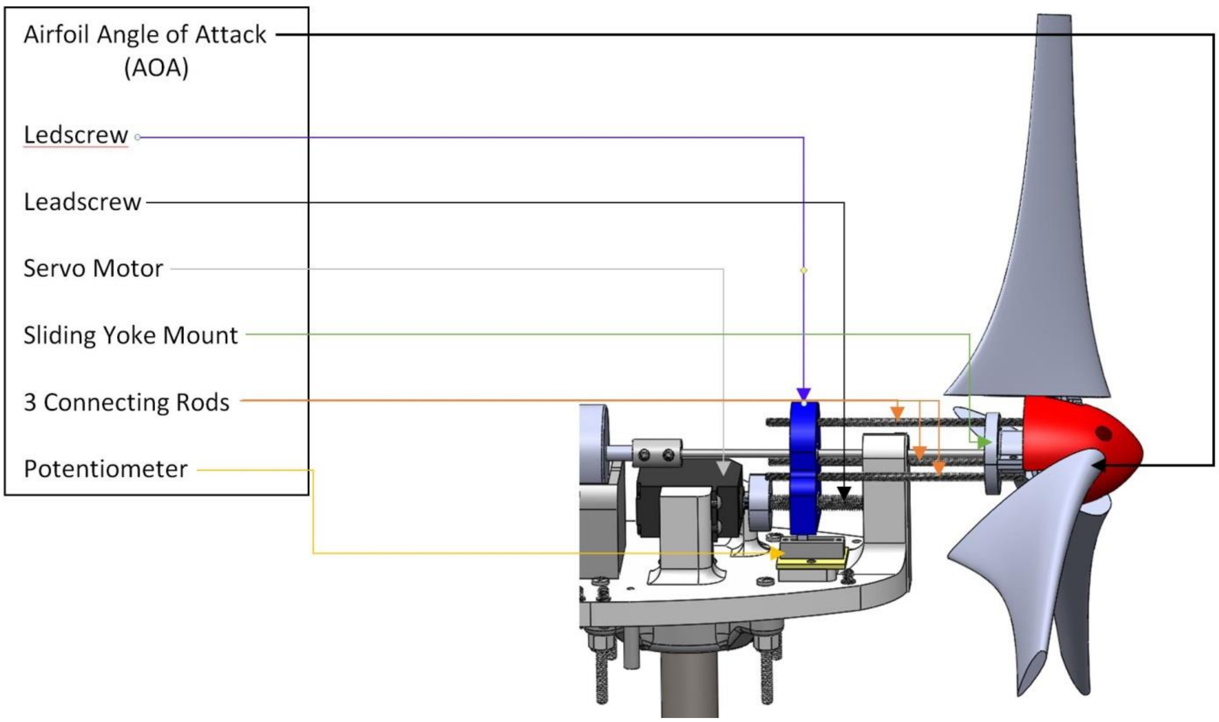


Figure 4: Sliding Yoke System

Three connecting rods are attached 120 degrees apart on the sliding yoke in order to move the blades equally along the drive shaft that connects the hub to the generator.

Yaw Design
The yaw design of the turbine is based on a passive control system. A wing on the back of the nacelle serves as the control surface. A double stacked angular ball bearing is press fit on to the tower via the inner race. The outer race is epoxied into a 3d printed “mounting jacket.” This jacket attaches to the underside of the nacelle. This two part system allows for both a low moment load on the bearing as well as easy adaptation to the fixed baseplate.

In order to have maximum swept area of the blades, the tower height is 50.6cm. By having the shaft of the generator lie upon the mid-plane, the blades have a longer maximum length. The outer diameter of the tower is 2.22 cm and has an inner diameter of 1.8 cm in order to allow the wires room to rotate freely. The bottom of the tower is threaded on the outside in order to connect with the base plate.

The passive yaw utilizes a wing that is attached to the rear of the nacelle. It connects at two points on the top and bottom. Two custom 3D printed mounts attach the wing to the nacelle via set screws. This design allows students to have a visual aspect to the yaw design. In addition, the 3D printed mounts allow students to attach different yaw designs. An FEA analysis was performed to determine the width of the mounts. Using PLA plastic there is a factor of safety of just over 2 for each mount at the maximum testing wind speed of 20 m/s. A pair of set screws connects the nacelle, mounts, and wing to each other.

Mechanical Loads

A custom induction generator was designed to maximize efficiency and flexibility for connecting various blades to the hub to enable in-depth wind investigations and aerodynamic studies and optimize learning opportunities. The key mechanical loads that were analyzed include the generator dynamic loads, ball bearings, and shaft torque, which were related to the blade's available mechanical torque.

To determine if the drive system rotates at the cut in wind speed a torque analysis done in Q-Blade. This information was used to determine the largest diameter the drive shaft. This shaft is a direct drive connection from the blades to the rotor of the permanent magnet generator. Another Q-Blade analysis was performed to find the theoretical torque and thrust that could be produced by the blades based on the above shaft design. 6061 aluminum was selected for the shaft due to its high strength and lighter weight than steel. To handle the axial and thrust loads applied to the shaft, a combination of thrust bearings and ball bearings were selected. The torque from the blades is the driving factor for the size of the shaft chosen as it directly correlated with the cut-in wind speed. The generator was sized based on a dynamic load analysis. Equation (1) was used to estimate the minimum torque required from the turbine blades.

$$T_{Blades} > T_{Shaft} + T_{Rotor} + 2T_B + T_{Bfield} + T_{Magnets} \qquad \text{Equation (1)}$$

Under dynamic loading the resistive torques, such as friction in the bearings, the rotational mass, and the opposing B field generated by the stator, were analyzed. T_{Blades} is the torque generated by the blades, 0.01 Nm. The sum of the resistive torques must be less than 0.01 Nm or the shaft does not spin and produce power at 3m/s, our target cut in wind speed.

Equation (2a) was used to calculate the torque of a bearing.

$$T_B = \frac{P \times \mu \times \mathrm{dm}}{2} \qquad \text{Equation (2a)}$$

Where P is the load bearing, μ is the coefficient of friction and equal to 0.0015, based on the American Roller Bearing Company for the resistive torque of the roller bearings (Friction & Frequency Factors), and Equation (2b) is used for dm. A safety factor of two was applied to the load calculations to prevent failure during operation.

$$\mathrm{dm} = \frac{(Bore + Outer\ Diameter)}{2} \qquad \text{Equation (2b)}$$

To calculate the resistive torque that the stator applies to the rotor, the magnetic field (B) of the arc magnet was needed. Since there is no formula to calculate B of the arc, an estimate was made using Equation (3) for a square block, shown in Figure (5).

$$\mathrm{B} = \frac{B_r}{\pi}\left[\arctan\left(\frac{LW}{2z\sqrt{4z^2+L^2+W^2}}\right) - arctan\left(\frac{LW}{2(D+z)\sqrt{4(D+z)^2+L^2+W^2}}\right)\right] \qquad \text{Equation (3)}$$

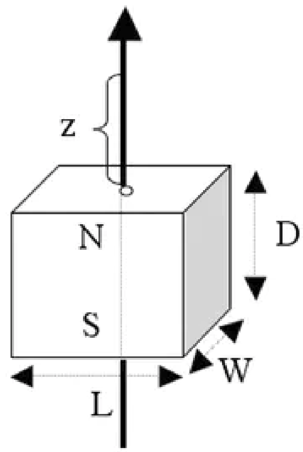


Figure 5: Free-Body Diagram of Magnet

A magnet arc of 60 degrees with outer diameter of 27.2 mm was used. The use of curved magnets necessitated an idealization of the magnets as rectangular, as shown above in Figure (5). The linear length of the magnet was calculated using Equation (4). The inner diameter was 23.3 mm, with a thickness of 3.9 mm.

$$w = \theta r \qquad \text{Equation (4)}$$

The distance between the rotor and the stator was set at *–z = 2 mm*, i.e. the air gap. Industrial standards use an airgap of roughly 0.1% of the rotor diameter; however a bigger distance was used to allow for tolerance issues and flexibility in alignment (Encyclopedia Magnetica).

With estimation for B, Equation (5) and Equation 6 were used to determine the current produced by the generator.

$$E = B \times A \qquad \text{Equation (5)}$$

$$E = I \times R \qquad \text{Equation (6)}$$

Where A is the closed loop area of the copper wire loop, or coils within the stator, I is the current, and R is the resistance.

The coil loop within the stator was idealized as a square, which gave an area of 40 mm x 20 mm. 28 AWG copper wire will be used during testing which has a resistance of 25.67 Ω per 1000ft (Common Wire Gauges). Each coil has 100 turns, in unraveling the coil and laying it out flat, the distance of the coil would be 41.6 ft at a resistance of 2.73 Ω.

When current runs through a wire it produces a B which opposes the B produced by the magnets (Walker). Equation (7) determines the B produced by the wire.

$$B_{wire} = \frac{\mu_0 I}{2\pi r} \qquad \text{Equation (7)}$$

Where μ_o is the permeability of free space (constant), I is the current in the wire, and r is the radius of B.

Equation (8), is used to determine the force required at the desired B distance.

$$\vec{F} = I\vec{L} \times \vec{B}$$ Equation (8)

To calculate the resistive torque of the magnetic field, T_{Bfield}, produced by the wire, the force was multiplied by r. The contributions of all the system torques are added to estimate the total torque required, which is given by Equation (9). (Schiavone, 415).

$$T_{Total} = (I_A + I_B + I_C + I_M)\alpha$$ Equation (9)

The mass moment of inertia is found via Equation (10). With m is the rotating mass and r is the radius of the rotating mass.

$$I = 1/2mr^2$$ Equation (10)

The angular acceleration was found from a force perpendicular to the rotating mass. According to Q-Blade the thrust, F_T, applied to the shaft is 0.05N. Equation (11) was used to determine the acceleration. Where $\dot{m} = \rho A v$ and Δv is the difference between tip speed and the base of the blade.

$$F_T = \dot{m}\Delta v$$ Equation (11)

Thrust is the result of the rate of change in momentum of the air upwind to downwind. From this torque can be estimated from Power=Torque*omega, where omega is angular velocity in radians/sec.

To account for the magnets on the shaft, each magnet has a mass of 47 g then multiply by 6 to get the total mass. Then take the height of the magnet and add it to radius of the rotor. There are multiple torques applied to the shaft as seen in Equation (9). With the calculations completed, the 0.825 Nm that is theoretically produced from Q-Blade is greater than the 0.14 Nm of resistive torque from the shaft. This concludes that the turbine shaft will begin turning in below 3 m/s wind speed.

Electrical Analysis

An 8 pole 3 phase AC induction generator has been selected and will be made in house with 24AWG 1010 cold rolled steel. The generator is made of individual slices to reduce the amount of eddy currents the generator would produce. According to Brian Sabalaskey from TruTech Specialty Motors M19 electrical steel is the industry standard, but using 1010 cold rolled steel between gauges 20-28 would be a good second option (Sabalaskey).

A radial flux generator design was selected because of its higher power capabilities compared to an axial flux generator design. It was also important to reduce the inertial load to improve low cut in wind speed performance.

To meet voltage requirements for the Arduino controlling pitch, a per phase coil turn amount of 250 was chosen. While a larger turn amount increases resistance in the machine more turns allows a higher voltage when the turbine runs at lower speeds.

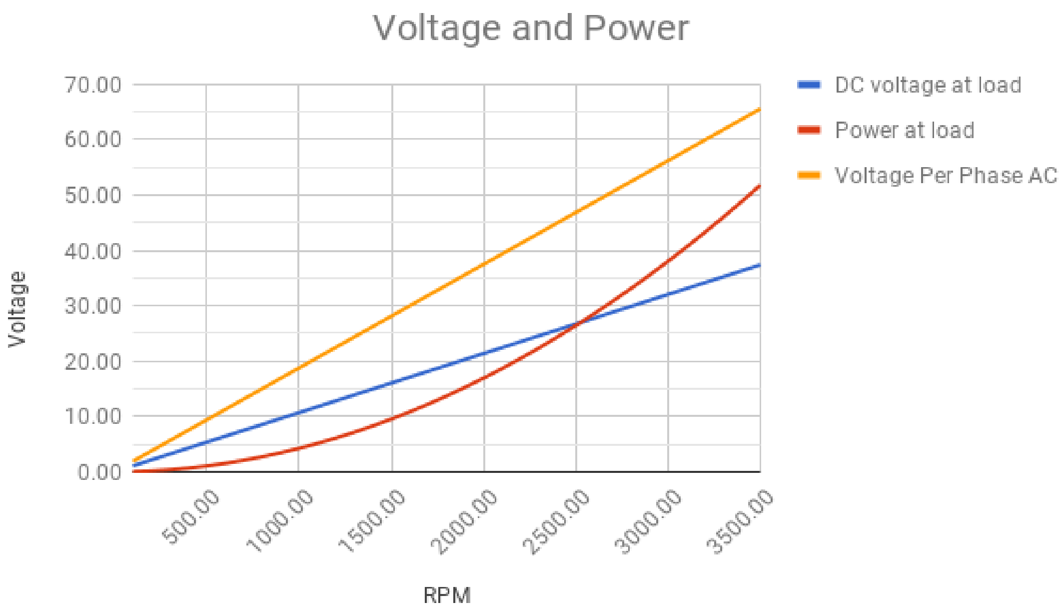


Figure 6: Voltage and Power Graph at 25 Ohms

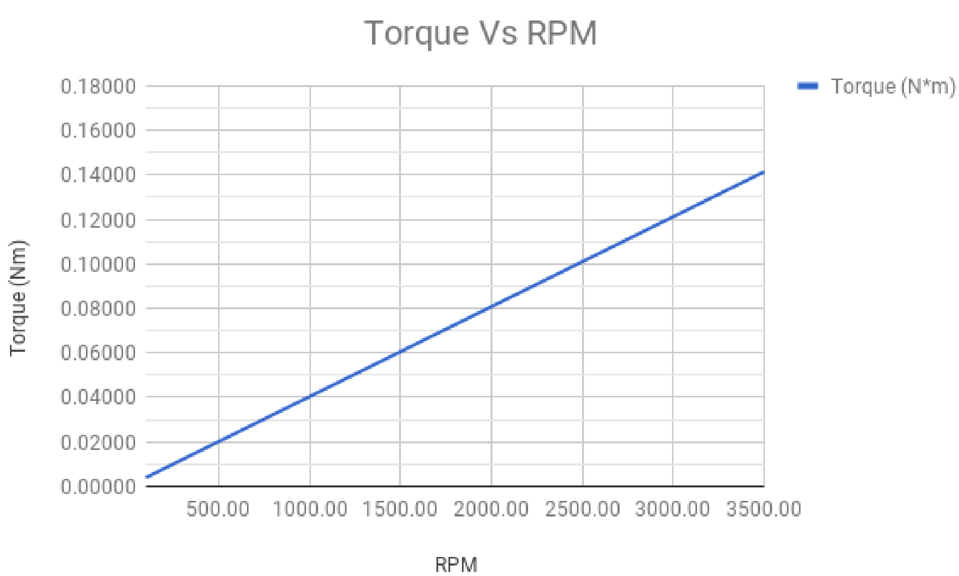


Figure 7: Torque Vs RPM

Based off of one coil at 1200 RPM results in 7.5v produced by the generator. Figures (6) & (7) show a theoretical prediction how the generator will perform over the different wind speeds. This generator was designed with a rectifier instead of a commutator for ease of fabrication and reduced cost. Generated AC is rectified to produce a steady, regulated DC voltage output.

Voltage Regulation

For reliable and complete functionality of the Arduino microcontroller, a voltage regulator was designed to control the output of the generator. Two stages of regulation are used; A synchronous monolithic buck regulator and a low dropout (LDO) regulator. The LT8619 is used for the first stage of regulation. This regulator is highly efficient, can deliver up to 1.2 amperes and has an input voltage range of 3 to 60 volts. The only fallback of the LT8619 is the output is very noisy compared to a LDO regulator. The LT3030 is used for the second stage to reduce noise from the LY8619 without losing efficiency that would occur if it connected directly to the generator. It has a low dropout voltage of 300mV, reduces the noise and has an Output1/Output2 that can supply 750 mV/250 mV respectively. Both outputs are required for the pitch control and sensors due to spikes in the voltage from the motor.

Turbine Load

For consistent test values we have a 25-ohm power resistor for the load. This value was sized so that it matched the impedance of the generator to provide maximum power output. The power of the turbine is measured with a voltage and current sensors. These values are read with a microcontroller that sends data to a Google Sheet to display the output.

The voltage and current sensors are used to monitor the power produced by the generator as well as to detect if the load is disconnected or shorted.

For the voltage sensor, two operational amplifiers shown in Figure (8), are used as buffers to output a voltage from 0-5V to the microcontroller. The ADA4522 amplifier was used for its wide range of operating voltages. The first stage uses the generator voltage to supply the positive rail and the non-inverting input. The second stage uses 5V to supply the positive rail. A voltage divider is used for the non-inverting input to assure the operational amplifier does not saturate. A potentiometer is installed for future adjustments based on operating performance.

Since both the positive rail and non-inverting are held at the same voltage, the output of the first stage will lose approximately 1.5V from the input. The output of the voltage regulator will have the following relationship in Equation (12).

$$V_{Sensor} = (V_{Gen} - 1.5V)(\frac{R2}{R1+R2}) \quad \text{Equation (12)}$$

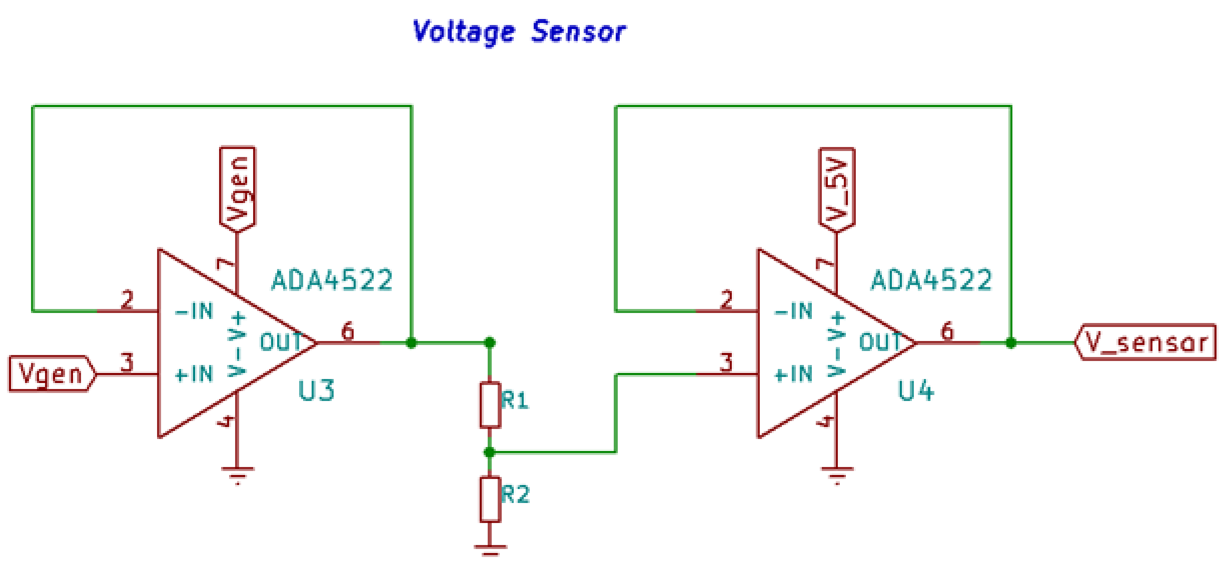


Figure 8: Voltage Sensor

For the current sensor Figure (9), a voltage difference amplifier will be used along with a current shunt resistor. The LT6375 is used for its high common mode voltage range and maximum gain error (0.0035%). For the circuit board design, all the reference pins on the LT6375 are made accessible for future adjustment of the gain. The output of the current sensor will be Equation (13):

$$V_{Sensor} = G \times i \times R_{Shunt} \qquad \text{Equation (13)}$$

G = Adjustable Gain

Where the gain of the difference amplifier, is the current to the load and is the resistance of the current shunt between the inputs of the difference amplifier.

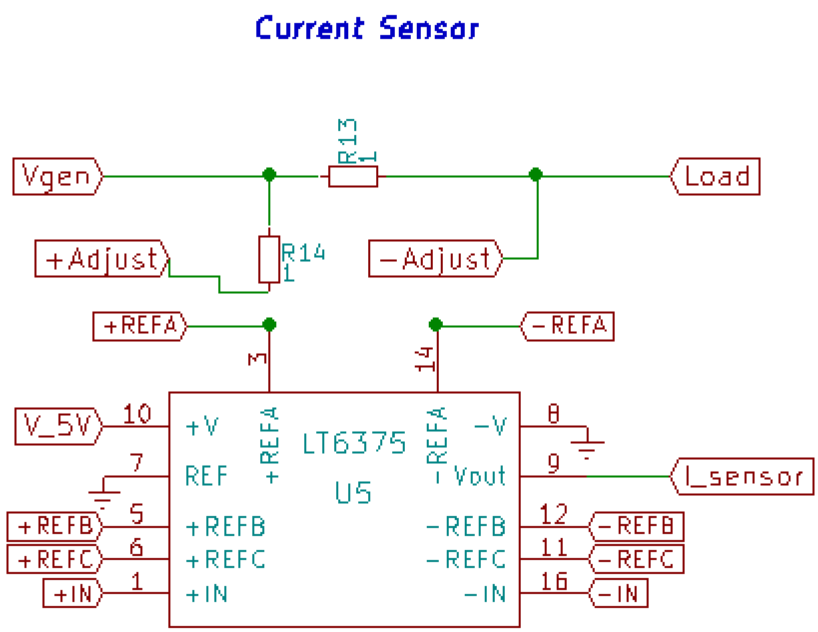


Figure 9: Current Sensor

RPM Sensor

A Hall Effect sensor is used to monitor the speed of the generator shaft. This is used as an input for the pitch control. Based on the torque needed for the maximum power output, the optimal pitch for the RPMs associated with the torque will be used as a “setpoint”. Once the optimal speed is reached, the pitch will be adjusted accordingly.

The RPM sensor is composed of two generic operational amplifiers and a Hall Effect sensor. This is commonly referred to as a tachometer. A small magnet is attached to the shaft of the generator, and the Hall Effect sensor is placed nearby. The voltage of the Hall Effect sensor fluctuates based on the position of the poles of the magnet. This voltage is used as the input of the first stage, which is used as a comparator. Interrupts are used by the microcontroller to count each rotation, so the output of the RPM sensor must resemble a square wave. A gain stage is needed to avoid multiple interrupts per edge.

Software Documentation:

The flowchart in Figure (8) describes the pitch control and emergency shut off sequence.

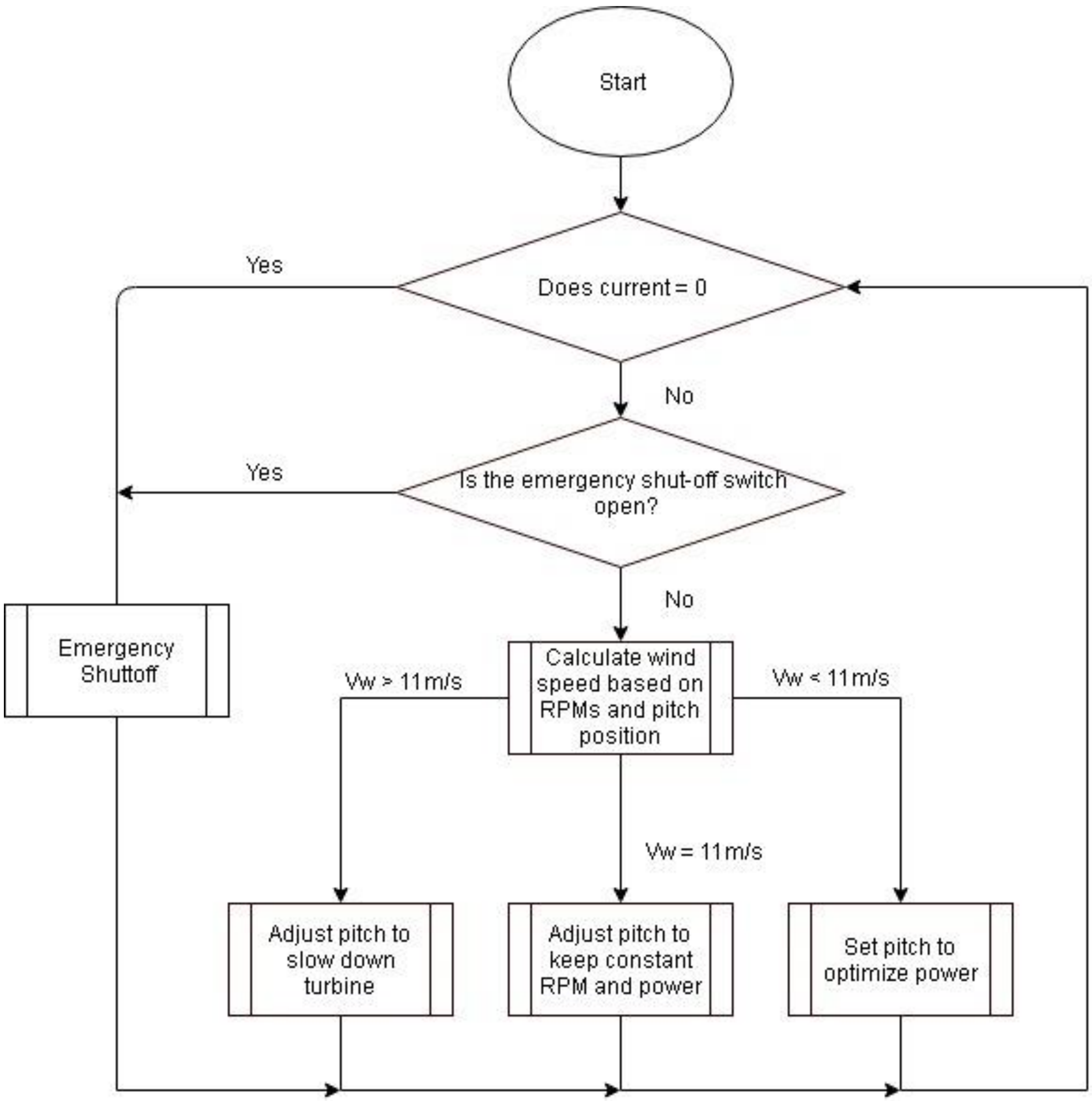


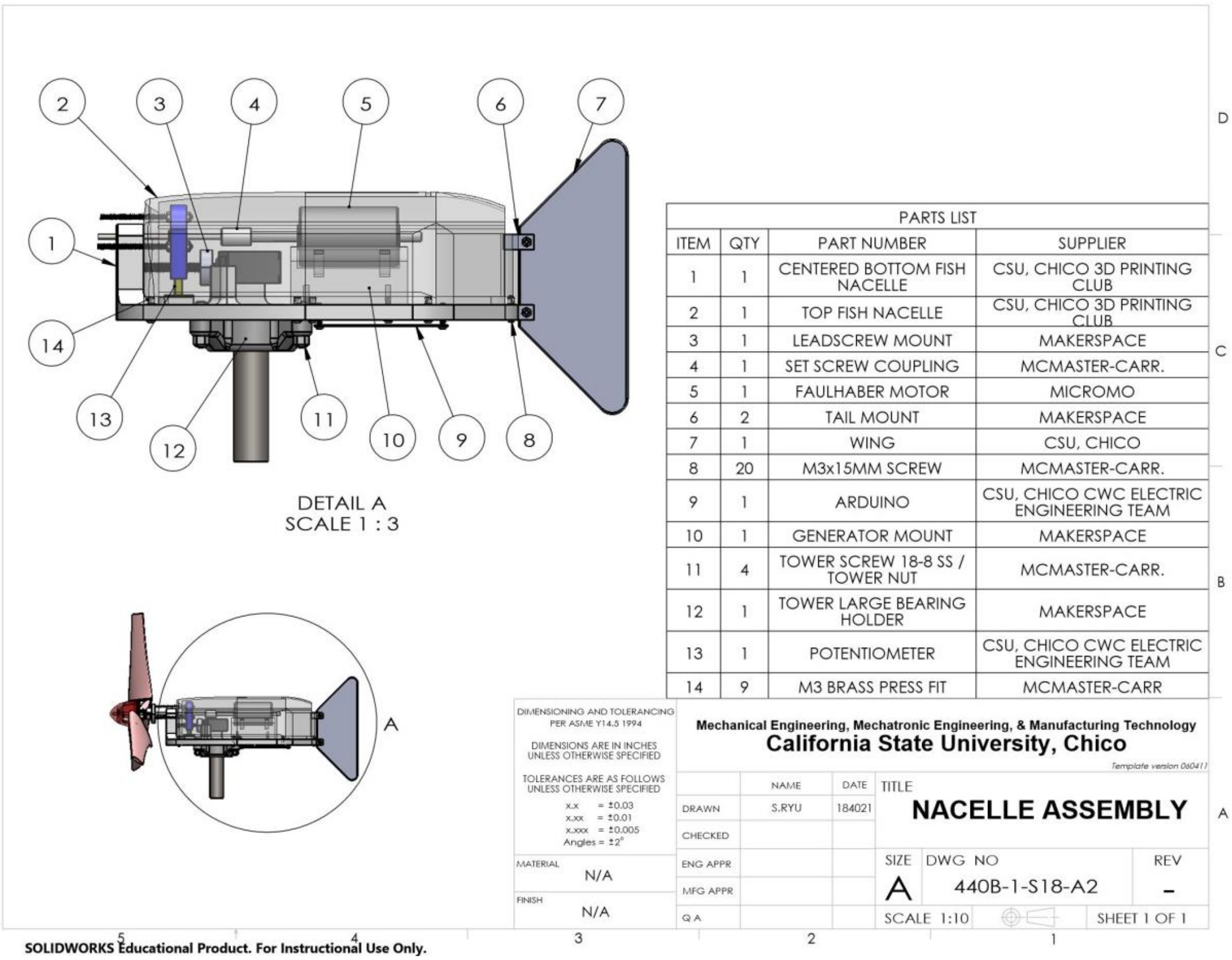
Figure 10: Arduino Flowchart

Results

A test of a prototype design was performed in order to prove the concept of the passive yaw. A freely rotating mass of roughly 5 pounds was placed upon a fixed tower. The connection between the tower and rotating mass was non-lubricated and high friction in order to drastically over-simulate the conditions of the final design. The CSU Chico 2017 CWC team's wing was attached to the 5 lb mass in order to represent the passive yaw system. The prototype was placed in the wind tunnel perpendicular to the wind direction. With the limitations of the wind tunnel on hand, the wind speed that the prototype became planar with the wind direction was marked down as the wind tunnel was powering up. After 5 tests an averaged initial speed of approximately 4 m/s was recorded; which satisfied our test requirement of being planar at a wind speed of less than 5 m/s.

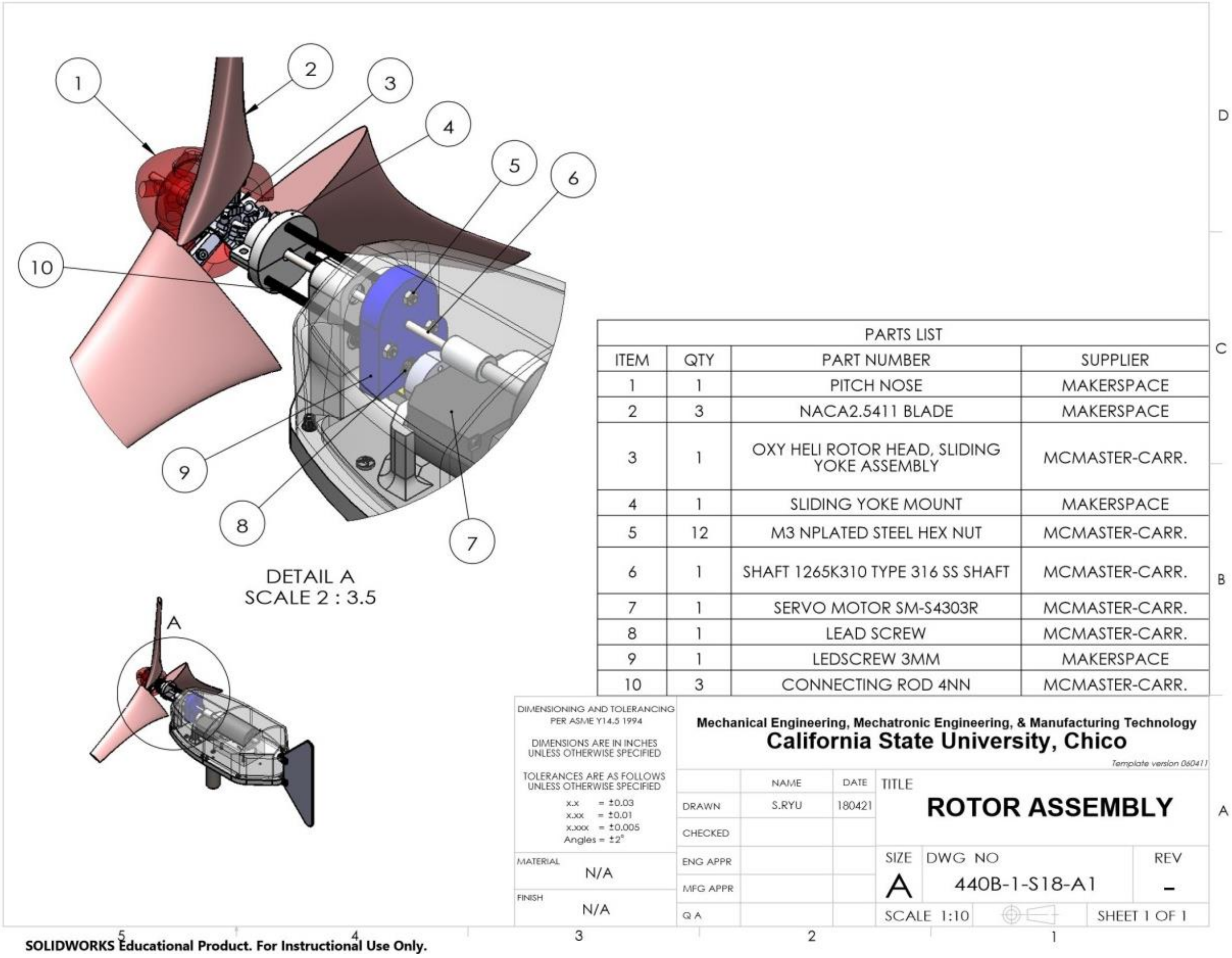
Engineering Diagrams:

Mechanical:



PARTS LIST			
ITEM	QTY	PART NUMBER	SUPPLIER
1	1	CENTERED BOTTOM FISH NACELLE	CSU, CHICO 3D PRINTING CLUB
2	1	TOP FISH NACELLE	CSU, CHICO 3D PRINTING CLUB
3	1	LEADSCREW MOUNT	MAKERSPACE
4	1	SET SCREW COUPLING	MCMASTER-CARR.
5	1	FAULHABER MOTOR	MICROMO
6	2	TAIL MOUNT	MAKERSPACE
7	1	WING	CSU, CHICO
8	20	M3x15MM SCREW	MCMASTER-CARR.
9	1	ARDUINO	CSU, CHICO CWC ELECTRIC ENGINEERING TEAM
10	1	GENERATOR MOUNT	MAKERSPACE
11	4	TOWER SCREW 18-8 SS / TOWER NUT	MCMASTER-CARR.
12	1	TOWER LARGE BEARING HOLDER	MAKERSPACE
13	1	POTENTIOMETER	CSU, CHICO CWC ELECTRIC ENGINEERING TEAM
14	9	M3 BRASS PRESS FIT	MCMASTER-CARR

Figure 11: Nacelle Assembly



PARTS LIST			
ITEM	QTY	PART NUMBER	SUPPLIER
1	1	PITCH NOSE	MAKERSPACE
2	3	NACA2.5411 BLADE	MAKERSPACE
3	1	OXY HELI ROTOR HEAD, SLIDING YOKE ASSEMBLY	MCMASTER-CARR.
4	1	SLIDING YOKE MOUNT	MAKERSPACE
5	12	M3 NPLATED STEEL HEX NUT	MCMASTER-CARR.
6	1	SHAFT 1265K310 TYPE 316 SS SHAFT	MCMASTER-CARR.
7	1	SERVO MOTOR SM-S4303R	MCMASTER-CARR.
8	1	LEAD SCREW	MCMASTER-CARR.
9	1	LEDSCREW 3MM	MAKERSPACE
10	3	CONNECTING ROD 4NN	MCMASTER-CARR.

Figure 12: Pitch Assembly

Electrical:

Figure (11) shows the one line diagram for the three phase electrical distribution system.

1) 3 Phase Generator & AC/DC Rectifier
2) Pitch Control
3) DC/DC Converter
4) Load

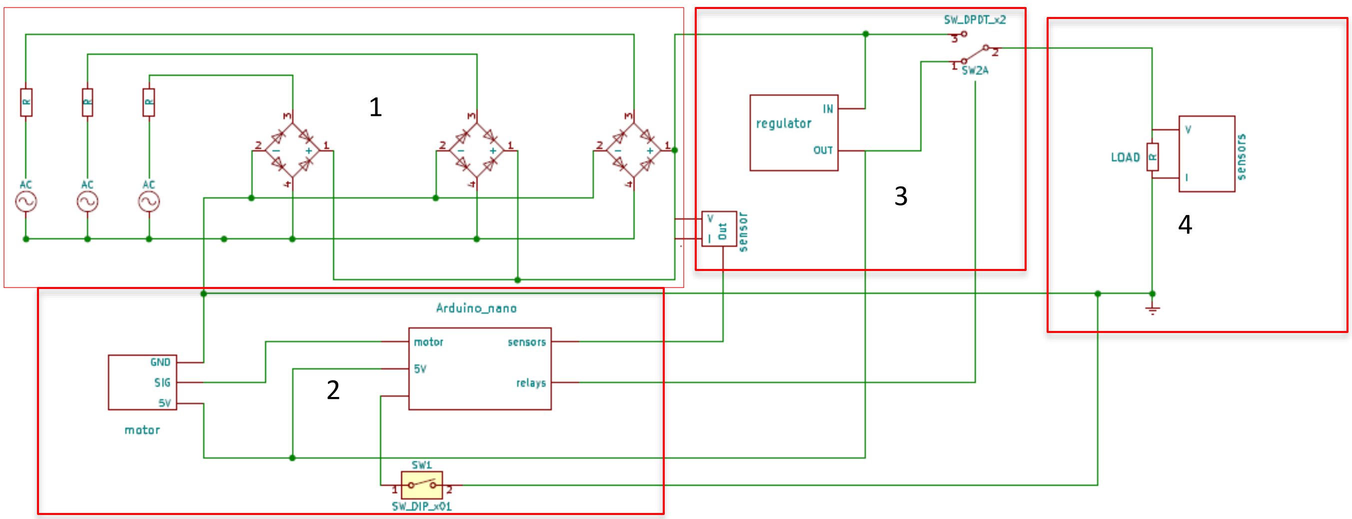


Figure 13: One Line Diagram

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