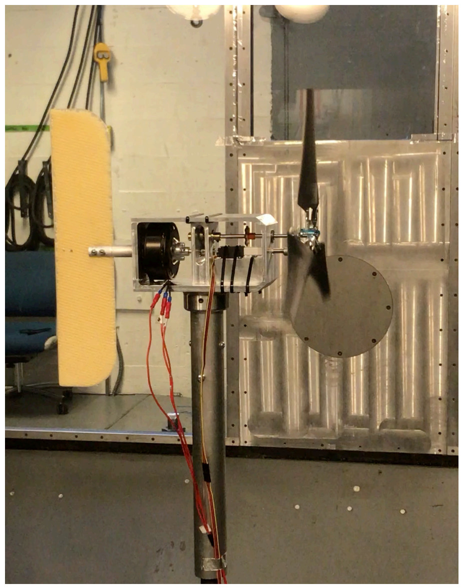
Collegiate Wind Competition 2019
Technical Design Report



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Executive Summary

Throughout the preparation for the 2019 Collegiate Wind Competition, the 2019 Seattle University (SU) technical design team has thoroughly researched, designed and built a small-scale wind turbine, SU.19, that can operate in an island mode and perform the five tasks outlined in the 2019 CWC competition rules and requirements manual. The SU 19 team consists of four mechanical engineering and two electrical engineering students each tasked with designing different components of the turbine.

SU.19 is a functional wind turbine with optimized blades, variable blade pitching, with a variable load and passive yaw capability, and a proportional power control. The blade designs of SU.19 utilized computational iterations using Qblade, an open source software for blade design and computational aerodynamic analysis, which produced the coefficient of power (Cp), lift, drag, and power curves. An optimization study was also conducted to examine how chord and twist parameters would impact the Cp values of SG6040 airfoil blades. The blades were 3D printed at 3D Systems using a proprietary resin to obtain a smooth surface and a high material strength.

A variable pitching system was implemented in SU.19. The team modified an off-the-shelf pitch control system for a hobbyist helicopter blade control to suit the needs of SU.19's design for variable pitching. The nacelle and tower were designed and machined to submitted not only to high wind speed of up to 20 m/s to observe for vibrations, but also to a finite element analysis (FEA) to establish their safety factor. A passive yaw system was also built with a 3D printed vane and roller bearings.

The electrical system of SU.19 can be divided into two fundamental categories: the generator and the circuit. The generator's main function is to transduce mechanical energy harnessed from the wind into the electrical energy. As, true generators are bulky and are not typically made for consumers and hobbyists, the SU 19 team chose to use 3-phase drone motors, which can be used as generators. The circuit of SU.19 was designed to fulfill two main goals: the ability to safely conduct the electrical load generated by the wind, and to be able to power the systems that monitor and control the mechanical and electrical components of the turbine.

The control system of SU.19 was designed to get inputs of voltage, current, power and RPM data, and to output commands to the pitching linear actuator to assure the turbine generates the power required by the competition. The proportional method was used to continuously modulated the control of the pitching system with an Arduino UNO Rev3 controller.

Due to the limited access to large-scale wind tunnels for testing of SU.19 in its full scale, its components were tested separately. A miniature blade turbine was also tested at the SU small-scale wind tunnel to examine the variable pitching system and the blade performance. Thus far, the team is still working through minor design changes to improve SU.19's performance and looks forward to the competition in May.

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1. Introduction

The Collegiate Wind Competition (CWC) is sponsored by the Department of Energy and organized through the National Renewable Energy Laboratory (NREL). NREL is the only federal laboratory dedicated to the research and development of renewable energy technologies. This competition exposes students to the developing field of renewable energy production. Renewable energy is an important up-and-coming profession that has evolved around the global need to reducing consumption of fossil fuels and limited resources. The goal of this project was to "...research, design, and enhance a turbine for a grid scenario with a high contribution of renewables and be able to operate in an islanded mode" [1]. Each year, the CWC identifies a new set of challenges to address real world scenarios, thus allowing students to demonstrate skills needed to work in the wind or wider energy industry. To prepare for the competition, the Seattle University (SU) team thoroughly outlined the five tasks of the competition and brainstormed and researched ideas to perform well in these tasks. Different aspects of each task were categorized into either mechanical or electrical engineering and then divided amongst individuals in the respective disciplines of the team. Ideas were then narrowed down into a single design, which was iterated upon multiple times before the manufacturing of the final turbine design. Once the turbine was manufactured, it went through testing, and the design was adjusted based on the results and observations from testing.

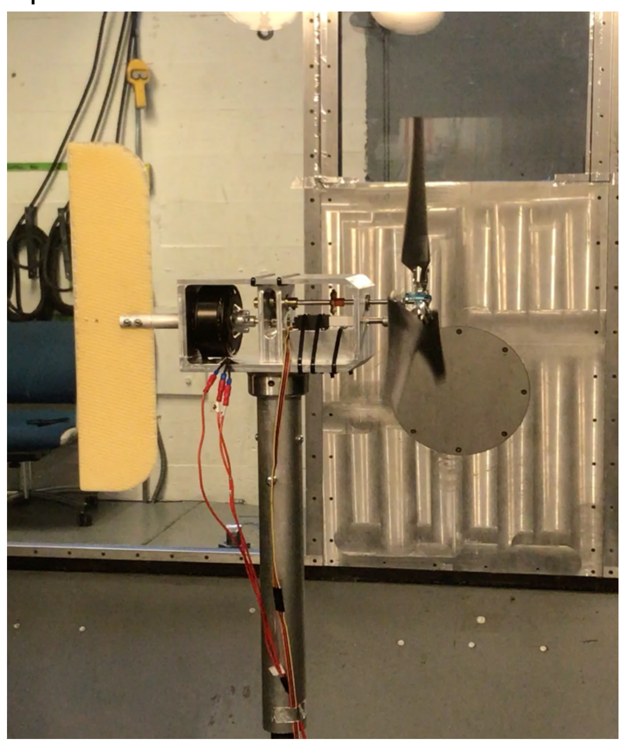


Figure 1: Image of the SU.19 wind turbine prototype

This report outlines the design components of SU.19. Since SU.19 leverages few parts from last year, this report provides an analysis of all the design decisions made while discussing the need of the modifications made to the previous design.

2. Mechanical System

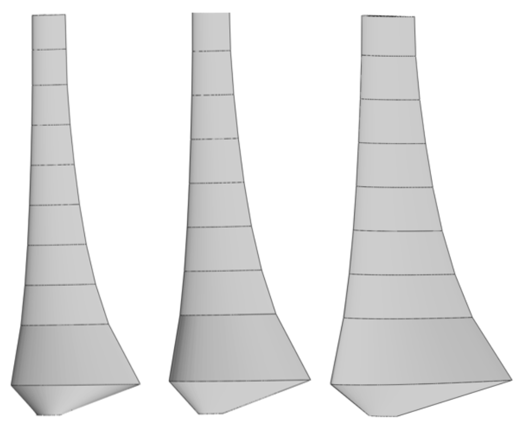
The mechanical technical design was divided into four aspects: blades, the variable pitch system, nacelle and the yaw system. This year, the design focused on optimizing the blades, implementing a variable pitch, lowering the cut in wind speed, producing constant power, and making the nacelle smaller and more aerodynamic. SU.19 was subjected to different tests to optimize and quantify its results. In this section, the designs of the mechanical system are described according to each of these four design aspects.

2.1 Blades

The blade design was done in QBlade [2], an open source software for blade design and computational aerodynamic analysis. As summarized in Table 1 with corresponding images for each iteation, the blade design process began by leveraging most of last year's design, which used a single extruded Selig and Giguere's SG6040 airfoil [3]. This airfoil was mainly chosen because of its structural integrity and its ability to operate well within low Reynolds numbers, low wind speeds and its use in small scale wind turbines. Since the SU 19 team opted for a variable pitch system, for the first blade made by this year's team, only the t-shape attachment from last year's blade design was replaced by a threaded shaft to allow testing at various pitch angles.

This first blade designed by the SU 19 team was to test power generation with direct drive connection between an off the shelf quadcopter motor and the rotor at the University of Washington of Seattle's 3' x 3' x 3' wind tunnel. This test also allowed the team to examine how varying the pitch of the blade impacted the power that could be extracted from the wind. It was observed that implementing a pitch angle between 30 and 35 degree increased the power production at the generator when spinning at approximately 3000 rpm. This was consistent with last year's testing results, which suggested a pitch angle of 30 degree. This test revealed that the SG6040 airfoil blade design could withstand high wind speed and produce sufficient power to support all the electric components. The results recorded during this testing allowed to calculate the coefficient of power (Cp), which equals to the rated power divided by the available power.

The second blade designed by the SU 19 team was based on the observations made from the testing results at the University of Washington of Seattle's 3' x 3' x 3' wind tunnel. The twist angle was increase as shown in Table 1, while the length of the blade was reduced to comply with the size constraint specified in the CWC 19



	1st Design	2nd Design	Final Design
Airfoil	SG6040	SG6040	SG6040
Length (cm)	20	18.3	18.3
Chord (cm)	6.44-1.25	6.44-1.25	8.37-1.3
Twist	30-5.38	30-5.38	(-26.87)-(-1.88)

Table 1: Three blade designs made by the SU 19 team

rules. The connection of the blades to the hub was modified to match the profile of the variable pitch system described in section 2.2. This second blade design led to the finale blade design, which incorporated an optimization analysis.

Trial	ΔChord [m]	ΔTwist [°]	Cp
0	0	0	0.355
1	+ 10%	+ 10%	0.358
2	+ 20%	+ 20%	0.355
3	+ 30%	+ 30%	0.350
4	- 10%	- 10%	0.345
5	-	+ 10%	0.342
6	-	+ 20%	0.330
7	-	- 10%	0.363
8	+ 10%	-	0.370
9	+ 20%	-	0.383
10	+ 30%	-	0.393
11	- 10%	-	0.335
12	+ 20%	- 10%	0.390
Excel GRG nonlinear solver solution			
13	+ 30%	- 10%	0.401

Table 2: Optimization studies

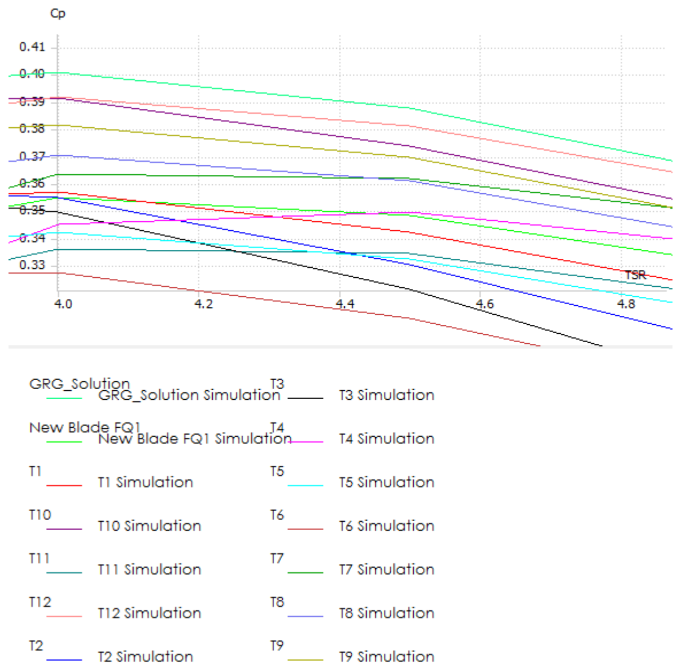


Figure 1: Qblade simulations for optimization studies

The blade optimization was performed to examine if the first blade design was the optimal design to produce the largest coefficient of power (Cp). The variables chosen in the optimization study were chord and twist. The optimized blade performance was evaluated in QBlade, and then a subsequent twelve trials, shown in Table 2, were evaluated in QBlade to determine their coefficient of power (Cp) values by changing the chord and twist parameters of the blade as

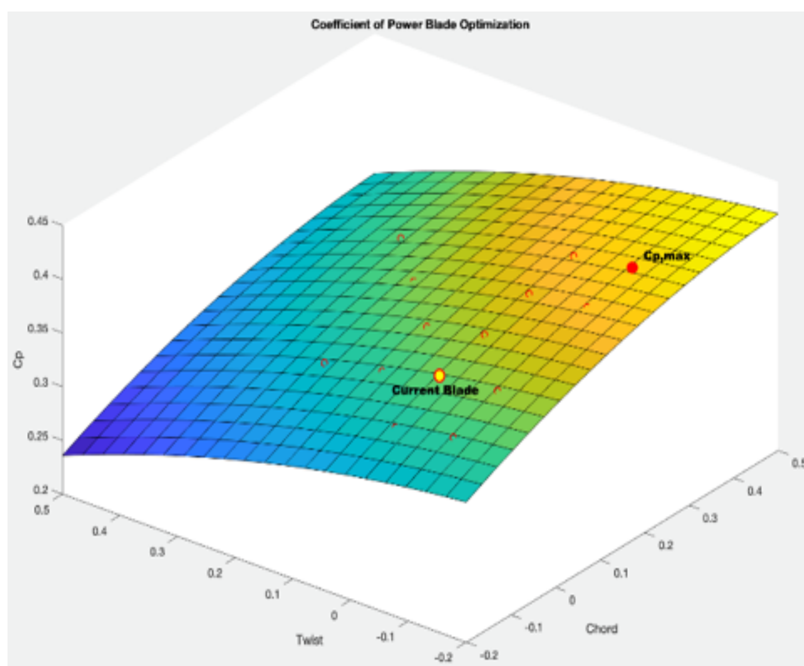


Figure 2: Cp values for given chord and twist from the optimization study

demonstrated in Fig. 1. Graphical optimization was then performed using MATLAB and Surrogate Assisted Optimization. The objective function that MATLAB output was then used to set up a gradient based search optimization in Excel.

Based on the graphical method results shown in Figure 2, it is easily visualized how increasing or decreasing the chord and twist parameters will affect the Cp value. The graph confirms that the optimal blade design incorporates 30% more chord than the first (current) blade with a 10% decrease in twist. This maximizes the Cp value to 0.401. This will result in a 12.96% increase in the coefficient of power over the first (current) blade design. Figure 3 shows the chord and twist distributions of the final blade parameters.

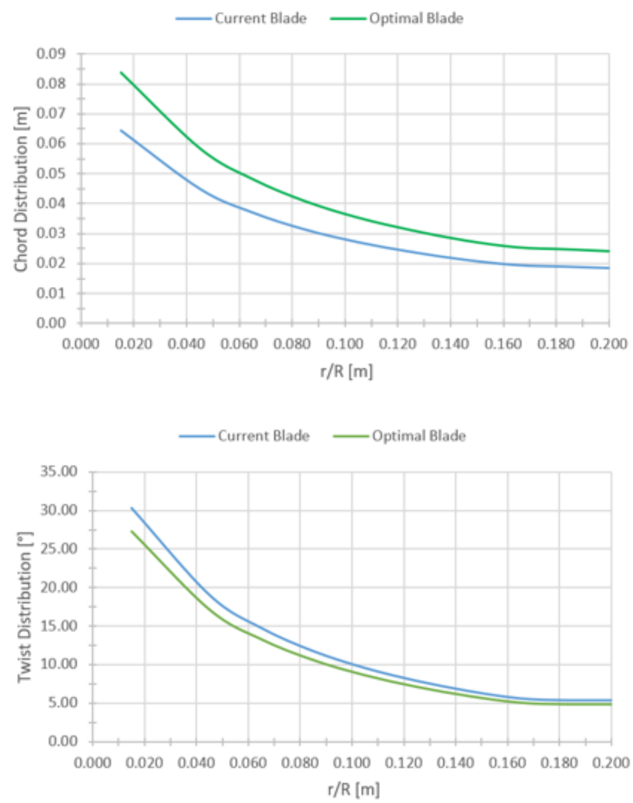


Figure 3: Chord and twist distributions of first (current) vs. final (optimal) blade

The comparison of Cp values for the three blade designs is shown in Fig. 4. The blades with the modified attachment to the hub shown in Fig. 5 were 3D printed by 3D Systems using a proprietary resin to obtain a smooth surface and a high material strength.

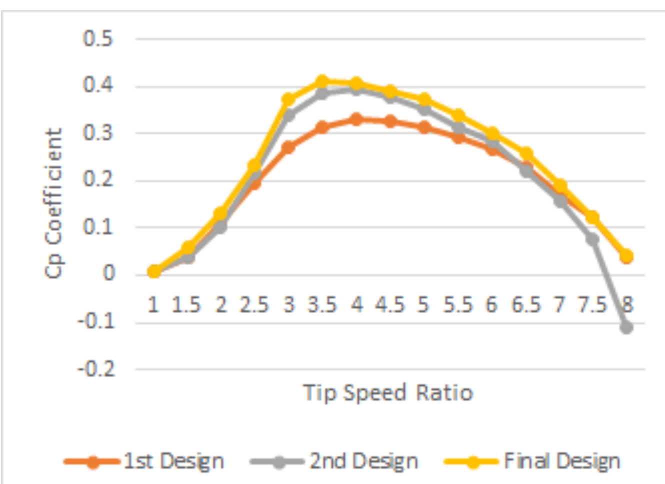


Figure 4: Comparison of Cp values of each iteration of blade designs

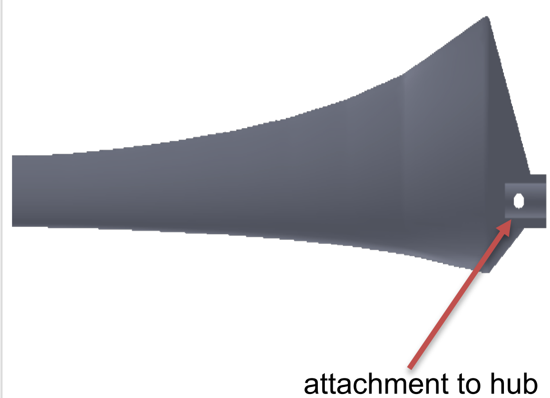


Figure 5: Blade design with the attachment to the hub

2.2 Pitching

Based on Seattle University's turbine performance last year at the CWC, one area for improvement was in the efficiency of the turbine. While there are many ways to improve efficiency, the area focused on here is implementation of variable pitch blade control. Starting with researching large scale wind turbines pitch control mechanisms, it was quickly realized it would be hard to design them for implementation on a smaller scale.

The first design approach incorporated using a hollow shaft and a pushrod to actuate a mechanical pitching mechanism. While this concept was more compact in design, it required using a passthrough generator so the actuator could be mounted behind it. Since an acceptable generator could not be found, and because of the complexity in manufacturing the small precision parts, this design concept was not implemented.

The final pitch control design came from examining how a helicopter uses blade pitching to control thrust. An off-the-shelf pitch control (shown in Fig. 6) was purchased since the cost was minimal compared to the time it would take to manufacture; however, several parts needed to be modified to make it work in for this particular application. The dogbone linkages shown in Fig. 6 were lengthened to achieve the range of blade pitch desired. Additionally, the original bell crank lever that controlled the pitch slider assembly was modified to accommodate a linear control.

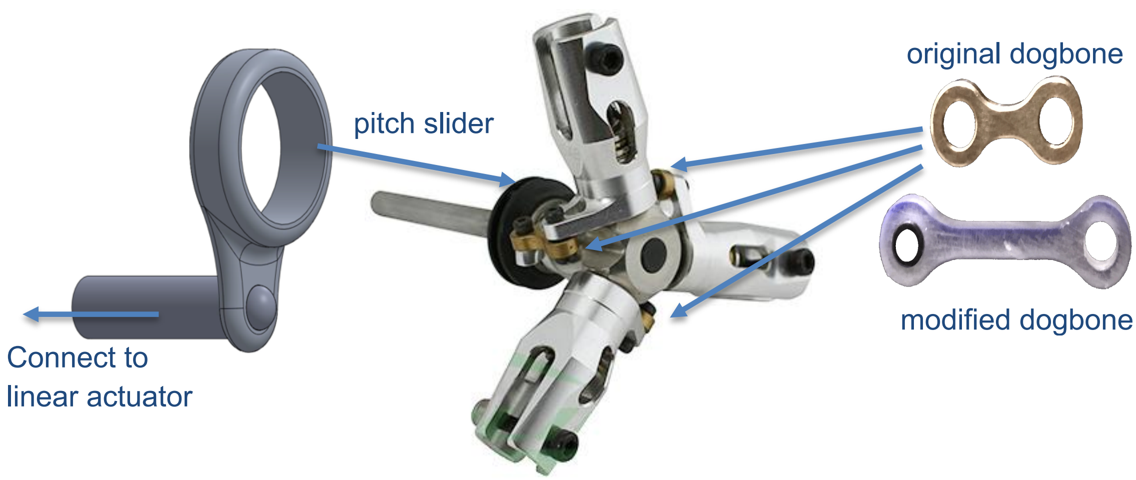


Figure 6: Pitching control

2.3 Nacelle

Nacelle houses most of components of the turbine system including the pitching control, the linear actuator, the generator and the shafts to connect them. After the selection of these components were finalized, the location to place each component was then determined to best utilize the limited space within the nacelle. To control the pitch of the blades, a linear actuator needed to be connected to the shaft that is connected to the hub. This shaft and the linear actuator are connected by a ring shape pitch slider (shown in Fig. 6), and to eliminate any bending moment in this ring, the linear actuator and the shaft need to be as close as possible.

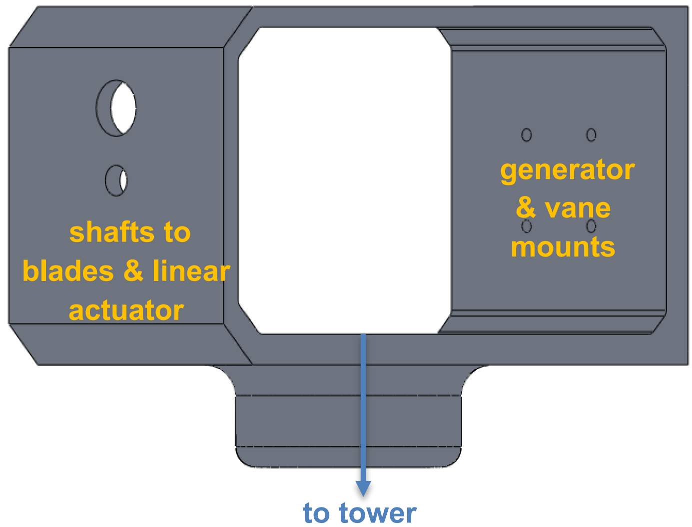


Figure 7: SU.19 Nacelle

A lower cut-in wind speed was desired, so it was decided that the nacelle would need two shafts, one attached to the blades, one attached to the generator, and both attached to different gears. Based on the generator curves and previous data, a gear ratio of 2:1 between the rotor and generator was determined. During earlier testing, heavy vibration with having the nacelle assembled as multiple plates bolted together was observed. Hence, SU.19's nacelle as shown in Fig. 7 was milled out of an aluminum block so that it will be one single piece. A hole in the base of the nacelle allows all wires from the generator and linear actuator to leave the nacelle through the tower, which is hollow.

2.3.1 Gearbox

According to the generator study presented in section 3.1, it was determined that in order to power the electronics as quickly as reasonably possible, a gear ratio of 2:1 was needed. Hence, the next step was to ensure the gears were meshed well at every instance of operation. Helical gears were chosen as they have more surface area to mesh. The inside diameters of the gears were chosen based on the shaft size of ¼ inch, and the number of teeth for each gear was chosen based on the desired gear ratio and the desire to have them be as small as possible. A gearbox was necessary for this design because the gears are small in scale, any misalignment could cause a poor gear mesh. By creating an aluminum T7075 gearbox shown in Fig. 8, the gears could move slightly along the shaft axially and still mesh well. Additionally, a small gearbox would allow the shafts to be supported by two bearings on either side of the gearbox, leading to easier rotation of the shafts. Furthermore, by including these extra bearings on either side, the shafts will not move

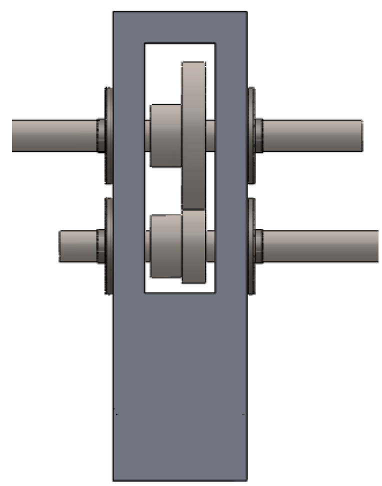


Figure 8: Gear box

vertically, and the gears will mesh at all times during testing. The gearbox is mounted to the inside of the top of the nacelle via bolts.

2.4 Yaw

The yaw system could be implemented in two methods, an active or passive yaw system. The active yaw system would require a more complex design approach with more electrical components. However, the passive system allows for the yaw adjustment solely from the wind during the competition. SU.19 was designed to use a passive yaw system which included a vane attached to rear end of the nacelle. The vane itself (shown in Fig. 9 (c)) was 3D printed with the assistance from 3D systems using a proprietary resin and polyurethane foam infill. An attachment on the back of the nacelle (shown in Fig. 9(b)), machined from aluminum T7075, allowed the vane to be fastened in place. This attachment piece has the same bolt pattern as the generator which allows for the same bolts to mount the generator on the inside of the nacelle as the attachment piece on the outside rear end of the nacelle. Since the vane is attached through this method, the wind could catch the vane as it passes over and around the nacelle to orient the nacelle in the direction of the wind.

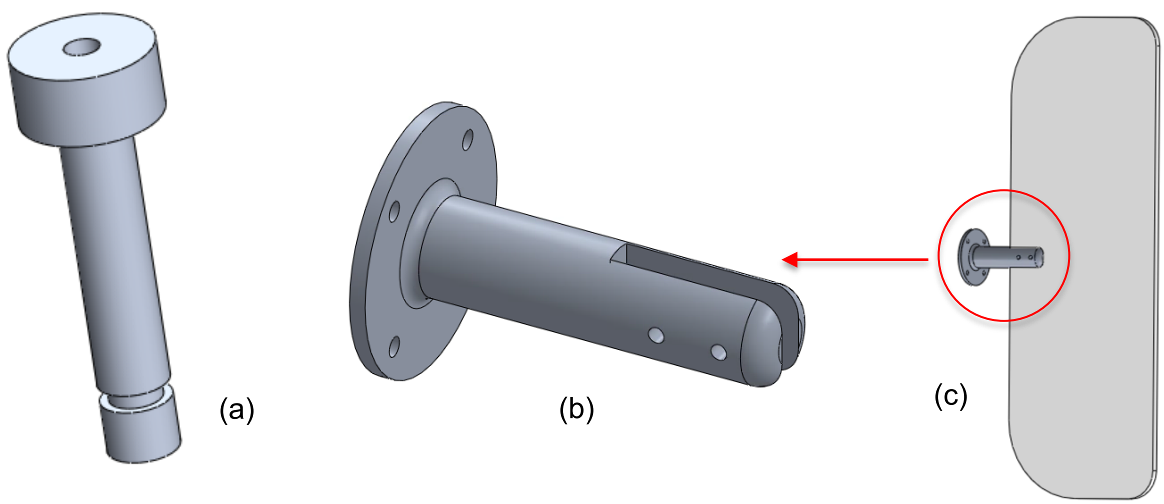


Figure 9: (a) Tower-Nacelle connector (b) Vane Mount (c) Vane

The next challenge with the yaw system was how the nacelle was going to spin. This was accomplished by machining a tower and nacelle connector piece out of aluminum T-7075 (shown in Fig. 9(a)). This piece fit inside the bottom lip of the nacelle and attached via bolts. Therefore, whenever this piece would rotate, the entire nacelle would rotate as well.

There are set screws inside the tower, which are the base for three separate needle roller bearings stacked on top of one another. These needle bearings have a slightly smaller outside diameter than the inside diameter of the tower. They also have a slightly larger inside diameter than the outside diameter of the tower piece, allowing for the tower and nacelle connector piece to slide into the bearings. The last necessary bearing was a roller bearing between the top of the tower and the bottom of the large section of the tower piece. This bearing is important to avoid a grinding of the tower piece and the top of the tower. By having a passive yaw system such as this, the whole nacelle can rotate at least by 180 degrees per second and can make as many rotations as necessary, the system is not limited to 720 degrees of total yaw. All these elements comprise the passive yaw system which has been confirmed to rotate at 180 degrees per second for 720 degrees of total rotation and accomplish the yaw component of the durability task.

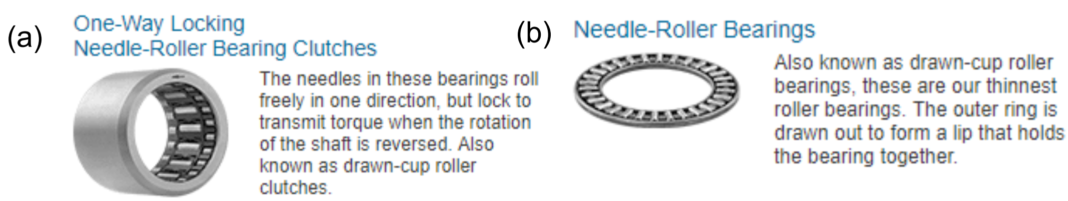


Figure 9: (a)Unidirectional bearing [4] (b)Thrust bearing [5]

3. Electrical System

The role of the electrical systems is important to the function of the turbine. The electrical system can be divided into two fundamental categories: the generator and the circuit. The generator's main function is to transduce mechanical energy harnessed from the wind into the electrical energy. The circuit has two main goals. First, and most primary, is its ability to safely conduct the electrical load generated by the wind. Second, but still important, it must power the systems that monitor and control the mechanical and electrical components of the turbine.

3.1 Generator

There are a lot of variables to consider for selecting a proper generator: number of windings, number of poles, max current, max voltage, etc. Since it is too time consuming to construct a generator from scratch, the real challenge the SU 19 team faced was finding something suitable that could be purchased retail. True generators are bulky and are not typically made for consumers and hobbyists. Therefore, the SU 19 team decided to look into motors with permanent magnets; so long as they employ permanent magnets they can be used as generators. DC motors were a design consideration because they usually come with motor encoders built in. This would have been a nice feature as RPM can easily be calculated. However, DC motors have many limiting factors especially as generators. Following suggestions from last year's team, SU 19 team looked into 3-phase drone motors. These provided a viable retail solution to procuring a generator.

Ultimately, the SU 19 team chose to go with the Xoar T8120 KV100 but a few different makes and models were purchased for comparison and testing. There were three main criteria for a good generator: maximum voltage, current capacity, and volts per revolution. For the maximum voltage rating, the T8120 has a maximum voltage rating of 44V. This is high enough to be competitive but limits before the competition threshold of 48V. For the ability to handle high current, the T8120 is rated to safely handle up to 50A of current. To reach a high voltage with a low number of revolutions, the lowest number of revolutions per volt - within the other two design criteria- was 100 r/v for the T8120. The specifications of T8120 satisfied all three criteria but it still required further testing to confirm its suitability for the project.

3.1.1 Generator Model & Analysis

The SU 19 team chose to empirically model our generators. This was done by attaching them to an industrial, variable speed, mill. By using series and parallel power resistors and three fluke VU meters the voltage, current and frequency of the generator was recorded into a spreadsheet at rotational speeds that range from 200 - 2500 RPM. Voltage was measured directly. Current was approximated by a one-ohm shunt resistor. And frequency was used in conjunction with Eq. 1 to calculate RPM. Voltage, current and frequency all follow a nice linear trend and are extrapolated at the theoretical operating point of 4000 - 5000 RPM. More details about the generator and its performance metrics can be seen in Appendix A.

$$f_m = \frac{120}{P} * f_e \mid P = Generator\ Poles \qquad \text{[Eq. 1]}$$

While the T8120 is a great selection for the generator, it really was meant to be a motor. Most generators have large permanent magnets. The T8120 does not have this. The magnets are relatively small in size. This means that it does not generate a strong magnetic field in the armature and thus the current it creates is relatively small. So, while it may be able to handle 50 amps, getting it that high is next to impossible using it as a generator. The upshot of this is that bigger permanent magnets make it hard to turn the rotor. Thus, the T8120 is easy to spin. While it may not generate an excessive amount of power, it does have the potential to generate a competitive amount and the team hopes to make that up in the cut-in wind speed and reduced rotational friction. It is also a 3-phase system. This means it must be rectified but it also means it is AC up to the point of rectification.

3.2 Circuit

The circuit was designed around the requirements outlined in the competition rules as well as the needs of our programmable devices, sensors, and power regulation. The competition requires DC at the point of common coupling. Thus, the generator is rectified into a DC voltage by which the rest of the circuit is designed. There are two voltage regulators that power our active components, a voltage divider to step down and probe the voltage drop across the load, and a 100 Hz filter before the PCC. We also implemented a variable resistor to control the armature current through the generator, schematic and analysis in 3.2.2. There is a MOSFET in parallel with the rectifier in order to short the load during the shutdown sequence. Shorting the load will cause a large amount of current to pass through the armature helping to slow the generator down during a shutdown.

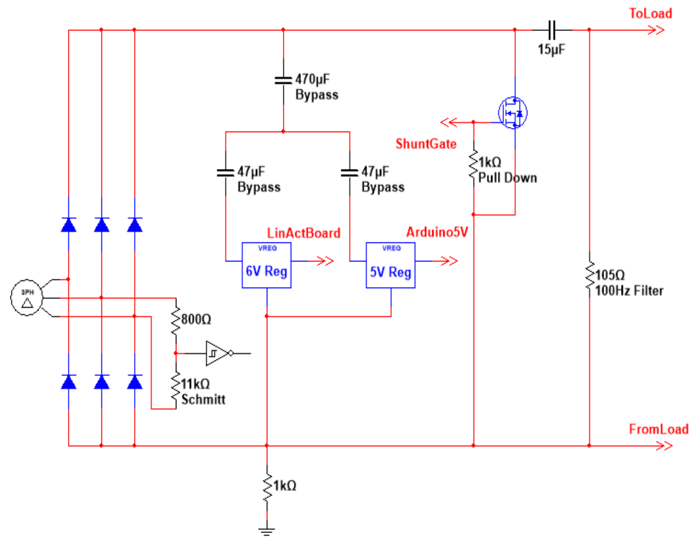


Figure 10: Circuit Schematic

3.2.1 Power Electronics

The rectification is handled through a high-quality IC chip that was purchased off-the-shelf. There was no rectifier component available in multisim so the six diodes accurately represent the rectification process but inaccurately represented as an IC chip. It is helpful to probe the generator line-to-line in the team's laboratory and testing setups to calculate RPM, but for the competition, building that into the design was tough. Calculating frequency from an analog measurement is no simple task. The electrical team toyed around with implementing a Schmitt Trigger to generate a pulse through hysteresis. The problem with the trigger is that it needs a voltage divider to step the AC down to $7V_{pp}$, this works at high speeds and high voltages, however at low speeds and low voltages the trigger does not cross its two threshold values in order to create a pulse thus the RPM sensor remains the source of RPM calculation.

The active components (Arduino controller, linear actuator, etc.) all require a constant voltage but with a variable current. Thus, voltage regulators are necessary. There are two in the circuit. This is due to the fact that the linear actuator requires 6V and it has a highly variable current. The Arduino prefers 5V and is sensitive to current fluctuations, therefore a separate voltage regulator is required. A star configuration bypass capacitor network is used in conjunction with the voltage regulators to help smooth the ripple from the rectifier. This helps cleanup noise in the current sensitive Arduino, ensuring accurate measurements.

Originally, there were two voltage dividers in the circuit. The first being the one for the Schmitt trigger, and is no longer part of the final design. The second serves to step down the voltage across our load resistor such that the Arduino's 5V maximum is satisfied. This voltage divider was designed by assuming that our generator would reach a maximum voltage of 40V. The standard voltage divider equation was used to calculate 5V at 40V. Having tested the power calculation at the Arduino, the team is confident this is working as planned.

3.2.2 Electrical Load Design and Model

One of the ways the electrical team chose to control power and armature current was a variable resistor. The component is realized by implementing a voltage controlled current. This is done by driving the gate of a MOSFET with a PWM duty cycle generated by the Arduino. The MOSFET is in series with the load resistor. This means that when the MOSFET is off the load is open circuit and the current through the generator is minimized. This will help during the cut in and shutdown tasks, The MOSFET requires a large amount of voltage at the gate in order to operate in saturation. This requires a gate driver. The gate driver requires 20V, which means there will be a power supply that plugs into an AC outlet on the load side of the turbine. The power supply is not in the schematic.

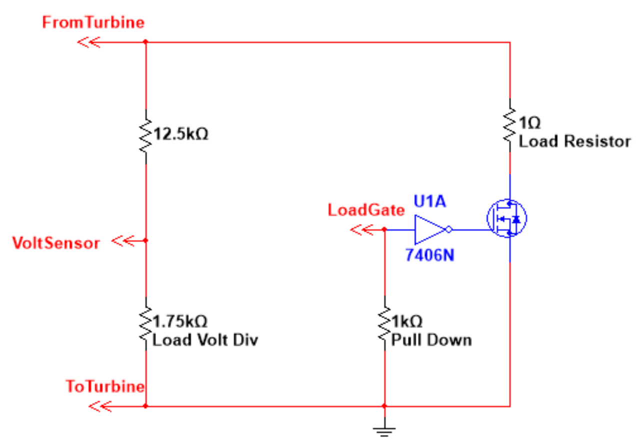


Figure 11: Turbine Load Schematic

The electrical team is still working on a model for the load. Since the team do not have the appropriate wind tunnel testing facilities, the generator cannot spin up to its max voltage. The team is currently working with a motor that has a large gear ratio. If this works, the team will be able to use special lab equipment that will allow the team to model the current and voltage the generator can supply and at what load resistance these parameters are at their maximum. Once the proper load resistor is identified, the team can begin to model the electrical load.

3.2.3 Analysis and Discussion

Operating voltage is a best guess at this point. The turbine has not been tested at operational speeds and the load resistor has yet to be finalized. Thus, the operative voltage is a floating value. The turbine can regulate the voltage into the load through a variable pitch blade control system. The control system will help to monitor and control the voltage generated by the generator by pitching the blades. The circuit and the load still need more testing and finalization.

4. Control System

The main purposes of the control system are getting inputs of voltage, current, power and RPM data, and outputting commands that help the turbine generating power values required by the competition. The commands include the control of a linear actuator which operates the variable pitch system.

4.1 Approach

The approach for programming the control system is applying the proportional method, which is a control loop feedback mechanism requiring continuously modulated control. A proportional controller is a type of linear feedback control system in which a correction is applied to the controlled variable which is proportional to the difference between the desired value (set point, SP) and the measured value (process value, PV). To control SU.19's functionalities, the team has a continuous loop in the Arduino code as demonstrated in Fig. 12. In the loop, first, it determines the maximum power value based on the data of wind speed calculated from the measured RPMs and the tip speed ratio. Then, it calculates the upper-bound and lower-bound of the desired power value, defined as +/-5% of the maximum average power. In the meantime, the Arduino continuously measures the power value at the moment. Each of the power value measured in a cycle of the loop will go through a set of if statements controlling the extension of the linear actuator to correct the angle of the blades so that it brings the current power value closest to the maximum power value, which also means to minimize the difference between the desired setpoint (SP) and a measured process variable (PV). The output power reading will be stable at the maximum average power value and the fluctuation will stay within +/-5% of this value.

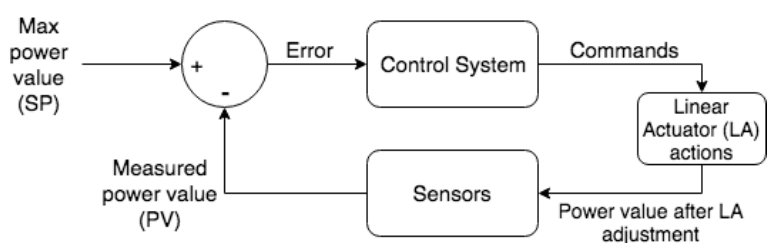


Figure 12 - Control Loop Block Diagram

4.2 Assembly

The control system consists of electronics parts including an Arduino UNO Rev3, an LM393 Tachometer, an ACS712 Current Sensor and an Actuonix Linear Actuator Control Board. Details of these components can be found in Appendix B. The Arduino Uno Rev3 was chosen to be the main processor of the control system mostly for its short initial boosting time and the ability to run a continuous loop as its default. The continuous loop is a wonderful fit for the approach of applying the proportional method to program the pitching system.

For the purposes of getting inputs, an LM393 Tachometer and an ACS712 Current Sensor are used to measure the shaft rotating frequency and the current generated from the generator, respectively. Voltage is measured directly by the Arduino as an analog input. Power is calculated as the multiplication of measured voltage and current.
A laser-cut encoder wheel consists of 8 holes is used to support the LM393 Tachometer. It is fixed to the geared motor and is placed in the slot of the sensor.

The Actuonix Linear Actuator Control Board (LAC) is used to control the linear actuator. This is a stand-alone, closed-loop control board specifically designed for Actuonix P-series micro linear actuators. The complete operation of the control system can be found in Fig. 13.

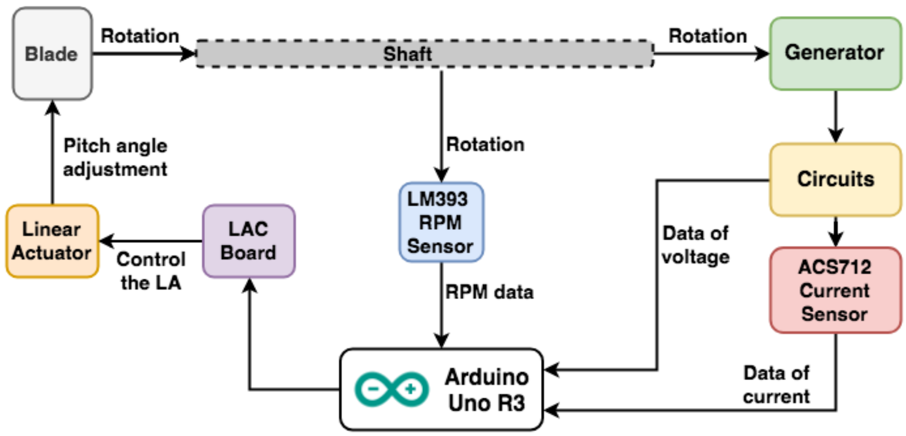


Figure 13: Control system schematic

4.3 Safety Shutdown and Restart

There are two additional functions implemented in the control program: emergency shutdown and restart. When the emergency stop switch is pressed or there is no voltage is detected at the load as the load is disconnected from the PCC, a signal is sent to the Arduino to initiate the shutdown. In shutdown mode, control system sends command to the LAC board to pitch the blades to the least power-efficient angle in the angle range of the pitching system in order to reduce the shaft rotating speed. To make sure the control system sill receives enough power to operate, the blades once having the least power-efficient angle do not stop the shaft completely but keep it rotate below 10% of its maximum RPM that generates the maximum power value.

The restart function is only activated when either the switch is un-pressed or the load is connected to the PCC and the emergency shutdown function has been activated. The function has the pitching system to pitch the blades back to the most power-efficient angle in order to instantly increase the shaft rotating speed.

These two functions are plugged in different places in the control code to make sure the system can recognize and take action as soon as an emergency stop is needed.

5. Results of Laboratory/Field Testing and System Analysis

5.1 Mechanical Load Analysis

5.1.1. Blade Loading

To ensure that the blades would withstand high wind speed without breaking, a stress analysis was done by making conservative assumptions. The drag was calculated by assuming that the blades were 20 cm x 5 cm x 0.3 cm. This simplified the calculations and increased the forces expected on the blades because the actual area was smaller. Eq. 2 was used to calculate the drag coefficient (Cd) of 1.185. The force on the blades was calculated using the drag coefficient, maximum freestream velocity, and swept area of the blades. These forces were run through Finite Element Analysis (FEA) to calculate the maximum stress and safety factor. Acrylic was used as the blade material for the FEA because the software did not have the properties of the actual resin used because of the proprietary constraint. This assumption was done based on the information received from 3D system, which suggested this resin had similar tensile strength as SLA and acrylic. This analysis shows a safety factor of approximately 15 relative to the ultimate tensile strength of the material.

$$C_d = 1.1 + 0.02\left(\frac{L}{D} + \frac{D}{L}\right) \qquad \text{[Eq. 2]}$$

5.1.2 Tower Deflection

SU.19 leveraged the tower from last year's turbine. An analysis of the deflection and stress of the tower was conducted to ensure the tower would not break while testing. The force on the tower has three components, the drag on the nacelle, the drag on the tower, and the thrust produced by the blades. For this analysis, it was assumed the nacelle was a rectangle measuring 20.3 cm x 10.2 cm x 9 cm. This simplifies the calculation of drag, and increases the safety factor, as the real nacelle should have a lower drag coefficient. The drag on the nacelle and tower were calculated using equation above. The thrust due to the blades was found to be 22 N, which was calculated through a QBlade simulation. These forces were then put into FEA Simulation to calculate the stress and safety factor of the tower. The results showed a safety factor of 15 relative to the maximum strength of aluminum.

5.2 Component Testing with Miniature Blades

SU small-scale wind tunnel was used to test the control system along with the circuit. Due to the size constraint, this testing was done using miniature version of the actual blades. The goal of this test setup was to ensure that all sensors were collecting the following data: current, voltage, rotor speed (rpm), and position of the linear. This setup also allowed to implement the variable pitching system and establish a default starting position for the blades.

Additionally, this setup allowed to compare the computational results to the field-testing ones. Since Qblade is able model performance curves of any blade design given certain variables, the power curves of those miniature blades were produced. At a wind speed of 20 m/s and 200 rpm, for instance, the computational results predicted a power of 0.15 W, the test revealed 0.11 W, or a percent difference of approximately 27%. These results informed the team that the blades performed as expected.

6. Summary

Over the last year, SU.19 was built. It is a horizontal axis turbine with a passive yaw, variable pitch, and three optimized blades. Its design required multiple iterations and testing of each individual part. Because of the limited access to a testing facility, SU.19 was mainly accessed using computational method. Further testing will be performed at the NREL facility to dial in final element of the control system. Even though SU. 19 is still a work-in-progress, the team continues to work on its design and overcomes obstacles. The team expects SU.19 to improve its performance at CWC 19 in May.

Appendix A: Electrical System

This appendix contains the diagram of the programmable devices and sensors as well as detailed information about the generator model.

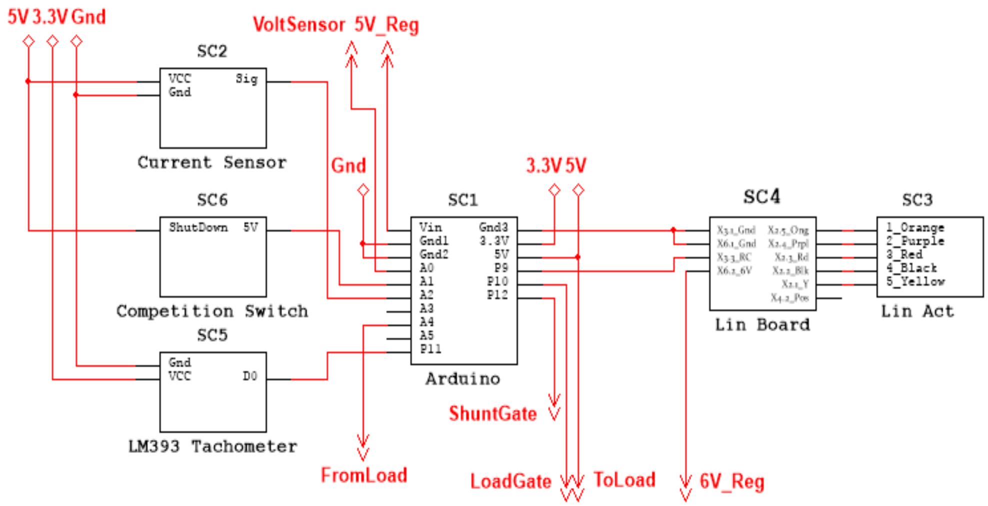


Figure A1 - Programmable devices and sensor connections

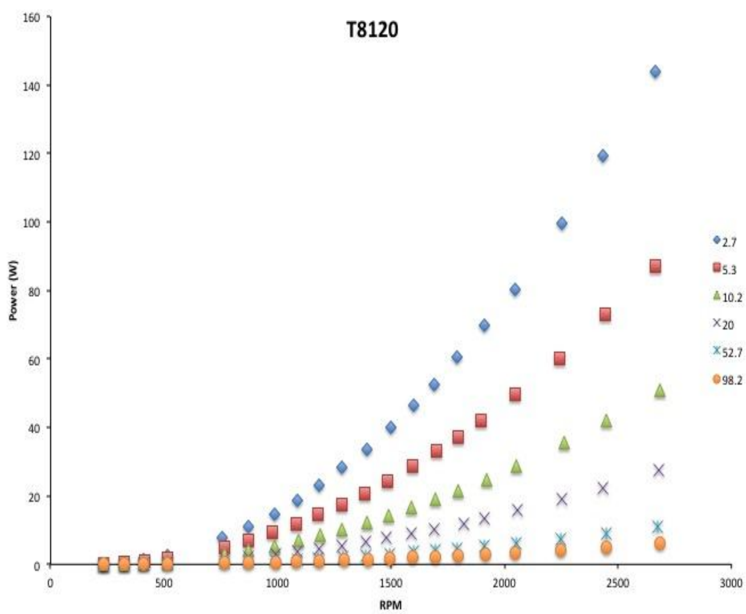


Figure A2 - Generator curves, (legend denotes resistance values)

Appendix B: Control System

Details of the control system are presented in this appendix.

Electronics components:

1. Arduino UNO R3

The specifications of the model are:

- Operating Voltage: 5 V; Input Voltage (recommended): 7-12 V; Input Voltage (limits): 6-20 V
- DC Current per I/O Pin: 40 mA; DC Current for 3.3 V Pin: 50 mA

Product can be found at: https://store.arduino.cc/usa/arduino-uno-rev3

2. RPM Sensor

For the purposes of getting RPM input, an LM393 Tachometer is used to measure the shaft rotating frequency. It takes 3.3V power supply from Arduino as its power source.

The LM393 Speed Sensor Module is basically an Infrared Light Sensor integrated with LM393 Voltage Comparator IC. The sensor part of the LM393 Speed Sensor module consists of an Infrared LED and an NPN Photo Transistor. These two components are placed directly facing each other, when there is no object in the slot, the light from the Infrared LED always falls on the Photo Transistor. The encoder wheel has 8 holes in it, so whenever the wheel makes one rotation, the infrared light from the IR LED is obstructed for 8 times from falling on the phototransistor. The signal from the phototransistor is given to the LM393 and based on the presence or absence of an object between the Infrared LED and the Photo Transistor, the Output of the LM393 IC will either be HIGH or LOW. The SIG pin on the Tachometer is connected to pin 9 of the Arduino so that the Arduino can receive the signal as a digital, and from here, calculate the RPM data.

$$RPM = RPS \times 60 = \frac{number\ of\ HIGH\ signals\ measured\ in\ 1\ second}{8}$$

Product can be found here:

https://www.amazon.com/gp/product/B01MRELRS1/ref=ox_sc_saved_title_9?smid=A30Y6WWS77DGEW&psc=1

3. Current Sensor

An ACS712 Current Sensor is used to measure the current generated from the generator. The sensor takes 5V power supply from Arduino as its power source. The current measured must stay within +-30A. The sensor corresponds to the analog output with the sensitivity of 66mV / A. The OUT pin of the sensor is connected to one of the analog pins on the Arduino.

The Arduino measures the input at the analog pin, converts it to millivolts, subtracts the offset and then finally divides it by the scale factor (the sensitivity) of the current sensor.

Product can be found here:

https://www.amazon.com/gp/product/B01N05BQ1T/ref=ppx_yo_dt_b_asin_title_o00_s00?ie=UTF8&psc=1

4. Linear Actuator & Linear Actuator Control Board

The linear actuator used in the project is the Actuonix L12-P Linear Actuator with Position Feedback. The L12-P line of linear actuators features an internal potentiometer for position feedback.

An Actuonix Linear Actuator Control Board (LAC) is used to control the linear actuator. As little as 1 digital or analog output is required for position control. A 6 - 24 volts power supply is required for operation. The same VDC used to power up the LAC will be sent directly to power the linear actuator.

As the linear actuator input must be less than 7V, a 7V VDC is used to power up the LAC so as to keep the linear actuator safe as well as maintain the stability of the LAC.

Products can be found here:

https://www.actuonix.com/L12-P-Micro-Linear-Actuator-with-Position-Feedback-p/l12-p.htm
https://www.actuonix.com/LAC-Board-p/lac.htm

References:

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[3] Seattle University 2018 Collegiate Wind Competition Team Report.

[4] https://www.mcmaster.com/one-way-bearings

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