James Madison University

2019 Department of Energy Collegiate Wind Competition

Technical Design Report

JMU Engineering Design Team

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EXECUTIVE SUMMARY

The James Madison University's Collegiate Wind Competition Team is committed to improving their performance by implementing lessons learned from previous competition experience and applying it to the 2019 competition at the National Wind Technology Center in Boulder, Colorado in May. As learning from experience involves reflecting and an opportunity to become better engineers, the senior engineering team is thankful to receive a second chance to improve their design. Throughout this past year, the senior team self-organized in order to increase the performance of their turbine, as well as advancing technical skills and re-grouping the management structure.

Since solving design problems is often an iterative process, the 2018 CWC design decisions were re-evaluated, including aerodynamic blade design, generator model, pitch and yaw mechanism, electrical design, and the controls system design. The test turbine is designed based on the requirements, constraints, and the performance objectives of the five testing tasks derived from the Department of Energy's Collegiate Wind Competition 2019 contest rules and requirements manual.

Because the requirements for the 2019 competition are similar to those of the 2018 CWC event, the focus was placed on improving the subsystems of the turbine into a fully functional turbine. Last year's design was improved by performing research and development through benchmarking, reviewing codes and standards, concept generation methods using directed search, and system integration testing and refinement.

Most of the individuals on the team are seniors and will be graduating, therefore, the goal is to continue creating more interest and awareness of wind energy to the JMU community and pass on the learned knowledge to a team of students in their third year to ensure a better future. Fortunately, thanks to the financial support from JMU Engineering and ISAT department as well as external sponsors such as anonymous donors and the Department of Energy, the students had the opportunity to transform into engineers as the JMU community continues to promote a sustainable world.

The document serves as the 2019 Technical Design Report, which explains the turbine's concept development process, as well as an engineering review of the associated design decisions of the turbine that will be tested in the competition wind tunnel. Beginning with aerodynamic design, this section unfolds the blades designed to enhance the aerodynamic performance of the wind turbine and consequently, increasing the generated power. Next, the generator model section covers rotor design, stator design, and prototype iterations. The structural design reveals the design features of nacelle and yaw mechanisms. Moving into the electrical design of the system, the engineering schematic reveals the power electronics chosen for AC/DC rectification, voltage regulation, and load model. Finally, the control model analysis consists of braking, pitch mechanism, and maximum power point tracking used to balance energy from the turbine as it approaches each task of the competition.

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1. TECHNICAL DESIGN OVERVIEW

The team focused on the main objective of designing an effective mechanical, electrical, and aerodynamic wind turbine and load design that is safe and reliable for testing in an on-site wind tunnel. Based on the five testing tasks, the team focused on tackling each task at a time in the order: cut-in speed, power-curve, control rated speed and rpm, safety task, and durability. The design objectives are formed to fulfil the functional requirements of the system, as well as achieve maximum points according to the CWC scoring rubric. The test turbine's design decisions are driven by the objectives to produce maximum power between 5 m/s and 11m/s wind speeds, regulate the power produced at each task, component selection based on the specifications, and system passes the safety pass inspection, and most importantly, all rules and regulations of the competition are met.

Seen in Table 1, the final product is a horizontal axis turbine consists of hand-made features such as a direct-drive generator, a passive yaw mechanism, an electrodynamic braking system paired with mechanical brakes, and incorporated with electrical and control systems. Compared to the 2018 design, both systems produce 32 watts; however, this design is improved by implementing a reliable control system.

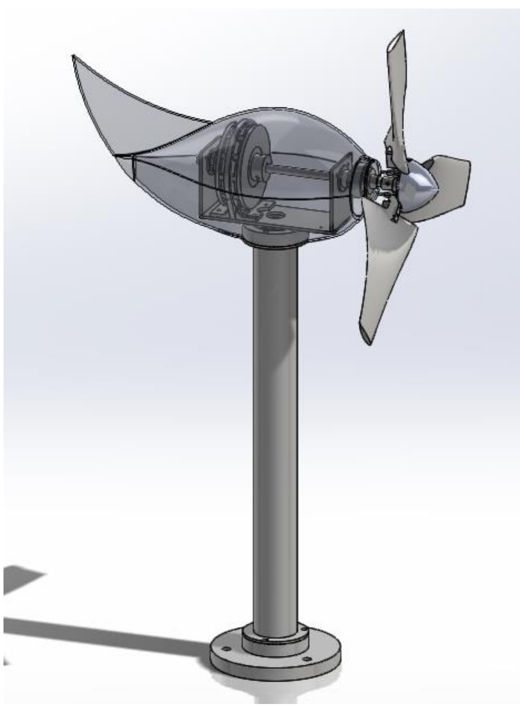

Figure 1 Test-Turbine Model

Table 1. Test Turbine Characteristics

Axis	Horizontal Type
Power	~32 watts
Cut-in	2.5 m/s
Rotor Diameter	0.45m
Rated Rotor Angular Frequency	1800 RPM
Blade TSR	2.5.
Generator Transmission	Direct Drive
Magnet to Coil ratio	4:3
Pitch Control	N/A
Yaw System	Passive
Braking System	Electrodynamic + Mechanical

2. <u>AERODYNAMIC DESIGN</u>

2.1 Blades

The blades are the subsystem of the wind turbine that convert linear kinetic energy from the wind into rotational mechanical energy that spins the generator to produce electricity. A horizontal axis turbine design decision was made in place of vertical axis designs due to higher achievable tip speed ratio (TSR). A single NACA 2413 airfoil was selected for blade design over ten different identified alternatives. Numerous blade element momentum (BEM) theory simulations were performed using Q-Blade, an open source wind turbine blade modelling package. A three blade 0.45 m rotor with blades attached to a 2.5-inch hub were selected in order to maximize the swept area of the blades while maintaining a hub size similar to the dimensional requirements of the 4-inch diameter generator. Last year, the generator's high torque requirement led to the utilization of a blade designed using the NACA 2413 foil and a TSR of 1.7. Following the competition, however, the decision was made that the blade in the future could sacrifice some of its toque in order for the blades to operate at higher rpm. This year's design followed this idea by utilizing a TSR of 2.5 with the same foil selection. With this higher TSR, the blade lost about an inch in chordwise length and operated at a much higher rpm. This operating rpm at 11 m/s went from ~900 rpm with the old blade profile to ~1800 rpm with the new blade.

When selecting a material for the blades, it was important that blade designs could be prototyped quickly, and the process would be easily replicated. To ensure both desires were met, the team decided early on to take advantage of the James Madison University 3D printing facility if possible. A lightweight and durable material was needed to ensure optimal performance at low wind speeds as well as sturdy support at high operating rpm. The blades were created using the Mark-forged Mark II 3D printer and Mark-forged's stock Onyx thermoplastic. Onyx is composed of Nylon and chopped carbon fiber. This duo of materials offers the strength and stiffness required with an enormous safety factor, as well as the lightweight attribute results of the turbine to function at low wind speeds.

2.2 Aerodynamic Analysis

When choosing the blade profile that the team desired most, analysis was made using Q-blade. One of the main things that was most important when choosing this blade profile was the potential power output of the blades. Figure 2 shows the power output of the blades in relation to the wind speeds that the blades are experiencing. The green line in this graph exhibits the blade performing at 1800 rpm, the test turbines operating rpm. Figure 3 shows coefficient of lift over the coefficient of drag versus the angle of attack of the blade profile and Figure 4 depicts the coefficient of performance in relation to the TSR of the blade design. All these analytics were pivotal to designing a blade that functions well at all wind speeds and provides enough torque for sufficient power output.

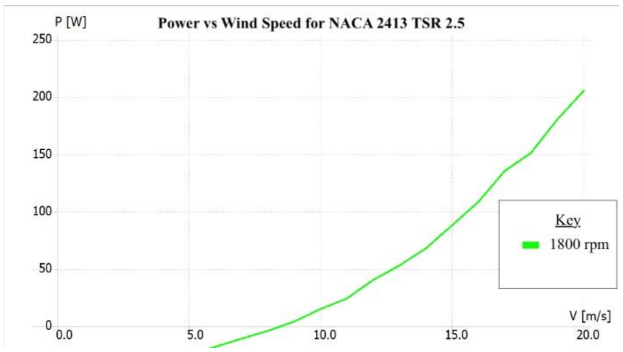

Figure 2. Power vs. Wind speed at 1800 RPM

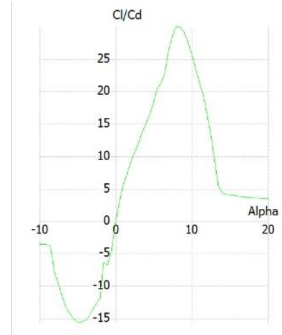

Figure 3. C_l/C_d vs. Alpha

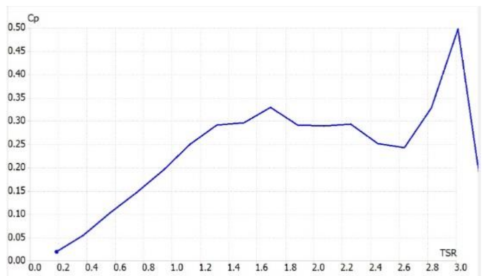

Figure 4. Cp vs TSR

2.3 Mechanical Loads and Safety Factors

The wind turbine blade material is a thermoplastic created by Mark-forged known as Onyx. This material is composed of nylon reinforced with crushed carbon fiber. This combination of materials creates a synthesis that can withstand any force that the blades will be subjected to in wind speeds ranging from 0 m/s up to 20 m/s. After running a flow simulation on SolidWorks at an operating condition of 20 m/s winds, the shear stress was determined to be 2.7 pascals. Since the Onyx has a tensile strength of 1.4 gigapascals, this material has a substantially high safety factor.

3. GENERATOR MODEL

Last year's generator design was among one of the positive takeaways from the competition. The generator had the ability to produce power that exceeded the team's goal power output. Knowing this, the team decided to use the same generator configuration for this year's design, seen in figure 5. The design is a four-inch diameter axial flux generator that contains 9 coils and 12 rectangular magnets. While the configuration was kept the same, the team was still able to control the generator power output and torque requirement by changing the air gap spacing between the rotors.

During the early stages of the year, the team explored a wye-delta wiring configuration that would switch between formations at certain wind speeds. The wye configuration allows for optimal high voltage output at lower wind speeds, while switching to the delta configuration would prevent the generator from exceeding the maximum 48 VDC output at higher wind speeds. With the wye configuration, the turbine was loaded down at higher wind speeds to remain under the voltage limit. However, this could be averted by switching to delta wiring and thus allowing the generator to produce the maximum power output it can generate.

By end of November 2018, the team decided to abandon the wye-delta switch configuration as there were too many variables and components to be considered and added for the remaining time before the competition. It was decided that the competition requirements could still be satisfied with the wye configuration and that the remaining time should be used on other components.

The power output performance for final generator prototyped can be seen in Table 2. All tests were done using a handheld drill and the RPM was measured with a tachometer. The voltage and current output were measured using a digital multimeter.

Table 2. Final Generator

Magnets	BX044-N52
# Of Magnets	12
# Of Coils	9
# Of Turns Per Coil	300
Testing Rpm	1260
Voltage	47.98 V
Current	1.47 A
Power	70.5 Watts

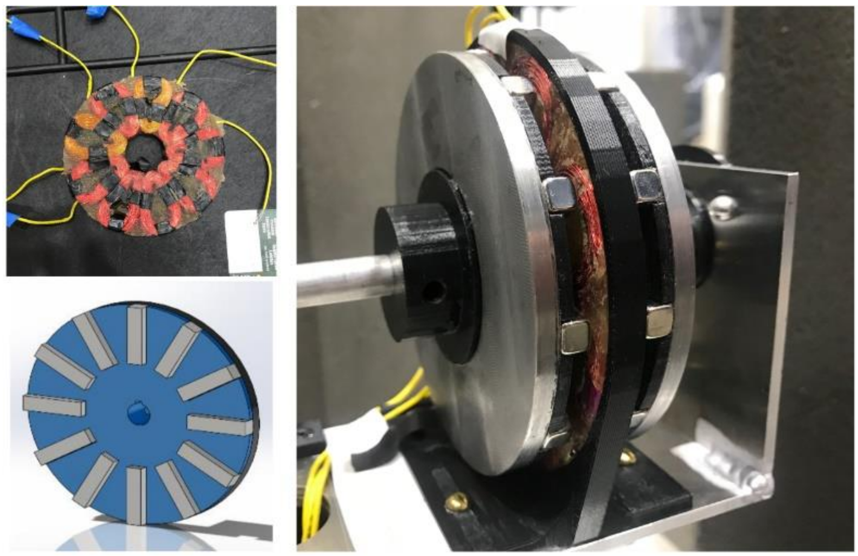

Figure 5. Generator Model

3.1 Rotor Design

The process of choosing magnets for the rotor design of the generator consisted of analyzing magnet strength, shape, and size. Neodymium magnets were determined to be the strongest available, so they were purchased and used for design iterations. During early stages of design decision making, both circular D82-N52 magnets and rectangular BX044-N52 magnets were used for design iterations due to the chosen size constraints for the generator. After testing procedures were conducted on both types of magnets, it was determined that the rectangular magnets would work best for the desired generator because they allowed for maximization of the coils' associated area. Its early iterations, a cast iron plate was used to back the magnets to increase the magnetic flux. It was observed through time that the cast iron plates warped, therefore, the team purchased magnetic stainless steel which allowed for the same function of the cast iron but was easily machined and was less prone to warping. A design objective that was identified was to minimize the required torque for rotation of the system which called for a minimization of magnetic stainless-steel backing. It was also imperative to ensure that the decrease in material backing did not compromise the magnetic flux density. The remaining area of the rotor consisted of ABS plastic 3D printed part instead of having more metal backing with a higher associated weight.

3.2 Stator Design

Several factors were taken into consideration during the stator design process, such as wire material composition, number of turns per coil, coil area, and stator thickness. Calculations were executed using Excel to identify the ideal coil gauge and number of turns per coil within the stator. Through these calculations, a 28-gauge wire with 300 turns per coil was selected. To maximize the available area, each coil was hand wound into a teardrop shape. This was done by 3D printing a mold into the shape of a teardrop and forming the coil to the desired specifications. The stator thickness controls the gap between rotors and affects power production. To reduce the stator thickness, coils were compressed and molded using fiberglass resin.

The stator mount design was changed from last year's three rod design (figure 6) to a bolted mount design (figure 7). It was discovered that last year's design negatively impacted assembly time inside the nacelle. With the new design, the nacelle components could easily be accessed for adjustments, removal, and installation.

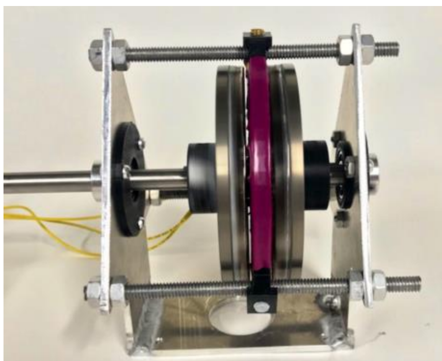

Figure 6. Three Rod Stator Mount Design

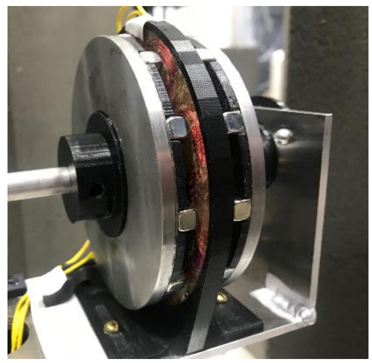

Figure 7. Bolted Mount Stator Mount Design

3.3 Generator Prototypes

Once the team understood which combination would produce the optimal generator, they refined the testing process for the generator. The most recent testing procedure consisted of the pairing of blades with the generator in a small-scale wind tunnel that was utilized on campus. The air gap between the rotor plates was adjusted to accommodate for different blade iterations, seen in Table 3.

Table 3. Spacing adjustment testing

Spacing	Cut-in Speed	Wind Speed	Power
0.7	2.60 m/s	7.00 m/s	9.78 watts
0.67	2.69 m/s	7.00 m/s	10.03 watts
0.66	2.59 m/s	7.00 m/s	12.30 watts

4. STRUCTURAL DESIGN

4.1 Yaw

The test turbine utilizes passive yaw to maintain its orientation into the wind. The passive yaw system is comprised of an inner and outer aluminum tube, two roller bearings, base plate, and a nacelle connector plate, seen in figure 5. The passive tower was machined and welded at JMU. Last year at the competition in Chicago, the protective rubber caps were removed from the bearings to decrease friction and increase sensitivity. This year, the rubber caps will not be removed, because last year there was too much sensitivity that caused undesired oscillation in the wind tunnel. Yaw movement results from a 3D printed ABS plastic wind vane on the downwind side.

4.2 Nacelle and Drive System

The test turbine utilizes a direct drive system. This implies that the blades, drive shaft, and the generator are all connected and on the same plane. The reason the team made this design decision was for the sake of simplicity and to avoid losses that are often associated with gear systems. The drive system itself is made up of two bearings, a shaft, and two shaft clamps. The bearings provide a support system for the drive system and provide as smooth a ride as possible to avoid friction losses. A slotted ⅜'' shaft was used for quick and easy attachment of the rotor plates and hub to the shaft using insertable keys. Finally, the clamps are used to prevent movement of the shaft within the bearings.

Last year, the team created a 3D printed nacelle for the turbine, but due to time restrictions were not able to create as aesthetic of a design as desired. The 2018 test turbine also featured a wooden wind vane that was a last-minute design installation for functionality rather than what the team desired. This year, the team plans to create another 3D printed nacelle with a more aerodynamic design profile that includes the wind vane as a part of the print. Seen in figure 8, this nacelle is projected to be easier to install and creating an aesthetic product.

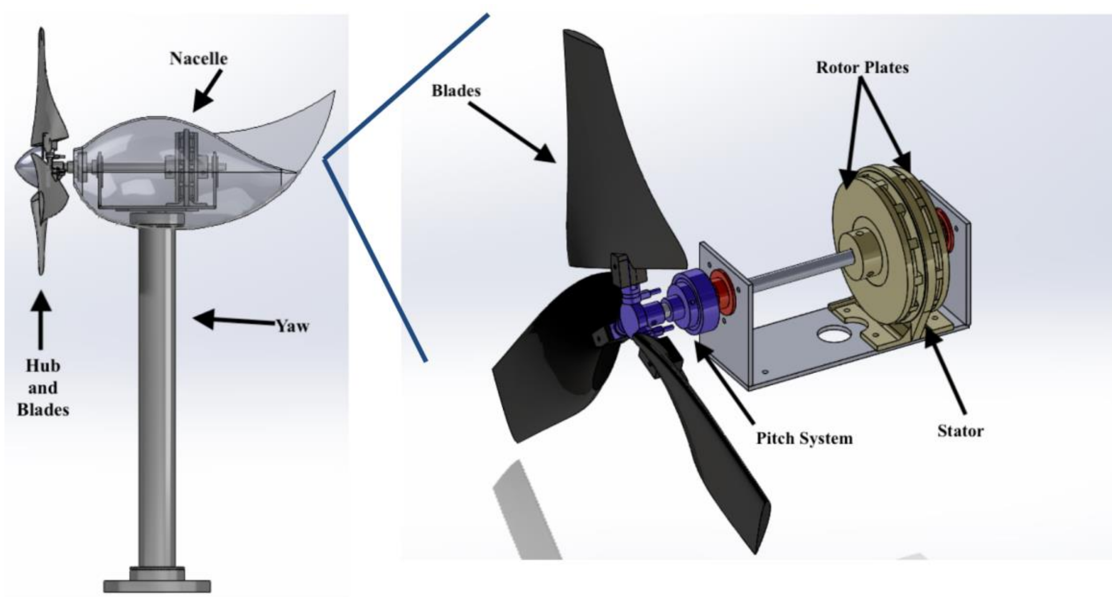

Figure 8. Structure Design of the system: Nacelle and Yaw

4.3 Material Selection

In order to design a turbine that can operate in the various conditions at the competition, a flow simulation was performed in SolidWorks, seen in figure 9. The simulation was used to determine the mechanical loads that the turbine will experience during the competition's harshest condition of 20 meters per second wind speed. The simulation calculated the maximum values for the shear stress, torque, and forces that the design will experience, seen in Table 3. Knowing these values, materials with appropriate mechanical properties were chosen for the design. The required properties during material selection were that the material had to be nonmagnetic and had a shear strength that allowed the design to have a safety factor of at least 10. Since aluminum satisfy both selection requirements and is very easy to be machined, it was the material chosen for the turbine's structural design. According to the simulation, the turbine will be experiencing a maximum shear stress of 8.0 pascals. With a shear strength of 207 megapascals, aluminum offers the material strength required with a safety factor substantially greater than 10.

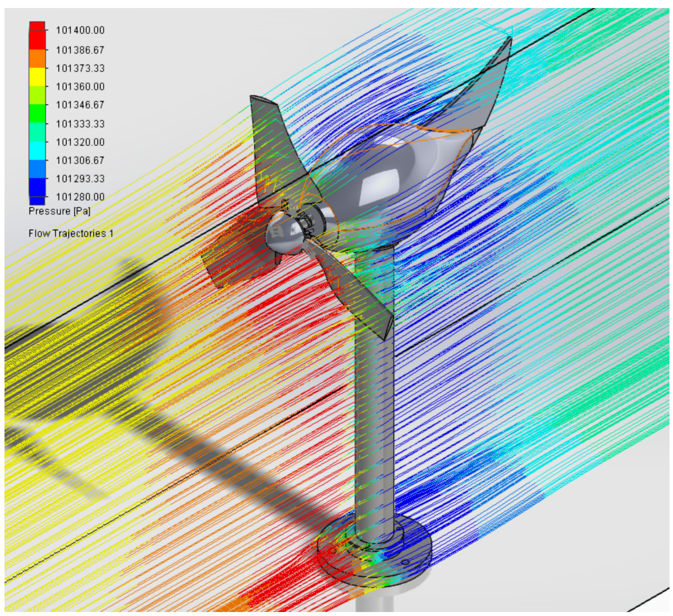

Figure 9. SolidWorks Simulation

Table 3. Material load testing

Simulation [20 m/s Wind]		
Goal Name	Value	Unit
Force (X)	0.2	[N]
Force (Y)	26.2	[N]
Force (Z)	22.2	[N]
Torque (X)	76.8	[N*m]
Torque (Y)	0.3	[N*m]
GG Torque (Z)	0.4	[N*m]
Force	34.4	[N]
Max Shear Stress	8.2	[Pa]
Max Shear Stress (X)	1.8	[Pa]
Max Shear Stress (Y)	0.8	[Pa]

5. ELECTRONICAL DESIGN

In order to design the electrical system, it was important to determine specific subsystems needed to balance the energy from the turbine. Seen in figure 10, a high-level model of the entire system was created to understand the flow and form of energy starting from the generator to the load. Each subsystem was black-boxed to visualize the major subsystems and the associated current and voltage specifications at each subsystem. The necessary inputs determined the component's functionality, while the voltage and current outputs were the goal of each component to fulfill in order to achieve system functionality. After the incoming and outgoing voltage/current values were defined, each subsystem was designed to with-hold these limits. The focus of this year was to ensure that the output of the system does not exceed the 48VDC limit to prevent disqualification.

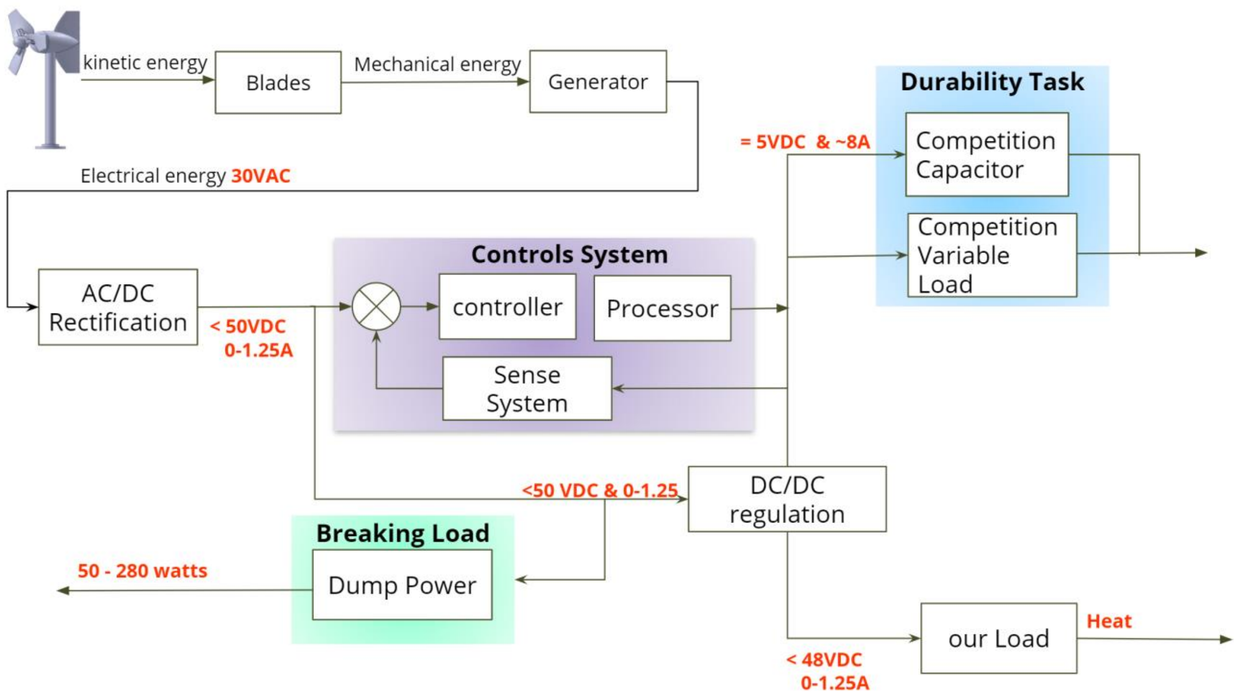

Figure 10. High Level Model for the entire system

5.1 Engineering Schematic

The electrical schematic can be seen in figure 1 of the Appendix. This schematic illustrates the power rectification, regulation, sensors, and control systems. For the "power curve" and "durability" tasks, a physical switch is used to transition between each task. The turbine will switch to the "durability" task from normal operation to maintain 5V output to the competition load. An LC filter is also incorporated right after the rectifier on the turbine and on the load of the PCC to eliminate spikes.

Last year, a slip ring with flange was used to allow twisting and rotation of wires safely from the generator to the NEMA box, allowing the turbine to yaw without damage to the wires. At the 2018 competition, the team realized that the slip ring with flange was an unnecessary component for allowing the turbine to rotate in full two rotations. In addition, wire management was a concern, that led to the goal of this year to be identified as improving wire selection and organization of the components. Stranded wires were chosen due to their associated flexibility compared to solid wire of the same total cross-sectional area. All electrical components, except the load and RPM sensor, were integrated as one circuit and housed in a NEMA Type 1 rated electrical enclosure. For the load side of the PCC side, an Arduino Uno, voltage sensor, current sensor, and electrical load is separately placed in another electrical NEMA enclosure. The load side control system is powered by an external power supply to ensure proper operation.

The electrodynamic braking system, Arduino Uno, voltage sensor, current sensor, DC/DC buck converter, are all housed on the turbine side of the PCC. Where the inputs are the three phase AC power from the generator, RPM sensor, and the motor for the electromechanical brake system.

5.2 AC/DC Rectification

From the output produced by the generator, the three phase AC is rectified to DC using a Schottky diode rectifier, paired with a capacitor to attenuate voltage harmonics at the output. Last year, we explored alternatives, such as Ideal Bridge Diode, and directed to a simpler system after the goal became to choose a component with less complexity to best operate with the overall system. The Schottky diode was chosen based on its 98% conversion efficiency, faster-switching time compared to silicon diode, reliability, and simplicity. Since the output from the generator is in three phases Alternating Current, it was then converted to Direct Current by a rectification circuit to meet the CWC competition requirement and provide usable energy to run the system.

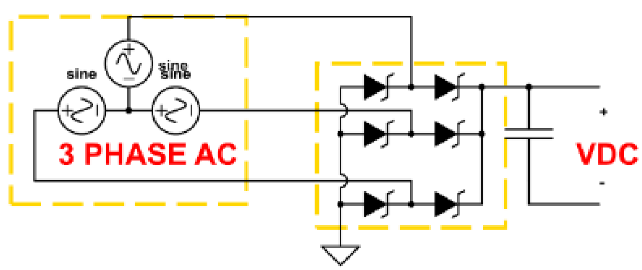

Figure 11. Three phased Bridge Rectifier

5.3 Voltage Regulation

Once rectified to DC, the voltage must be regulated to safely power the electrical components and regulate the output to the competition load. In the system there will be two separate DC/DC voltage regulators. One for the turbine side of the PCC sensors, microcontroller, and the servo motor that is used for the electro-mechanical braking. The other voltage regulator is used to step down the voltage to a constant 5VDC for the the competition load. The regulator for the competition load is rated for up to 60 watts which gives a safety factor of 1.5. This regulator is not operating until the durability task at which point the output must be as close to 5VDC as possible.

The 5VDC voltage regulator plays a critical role for the Durability Task. It must maintain a constant 5VDC at a wide range of input voltages and must output up to 40 watts. Currently the team is working to integrate charging and discharging the capacitor to maintain the constant 5VDC. This will allow the system to draw power from the capacitor when input power is below what the load is drawing to prevent the control system shutting down.

5.4 Electrical Load

The electrical load chosen for this year is a power resistor that models a heater that can be used as heater for heating water or heating a small room. This was chosen to simplify the system until all other subsystems where functioning properly and reliably. In the future, the hope is to redesign the load in such a way the load serves to inspire and serves as a prototype that solves a real-world problem.

6. CONTROL SYSTEM

The control system is responsible for fulfilling the various design challenges of the competition. This includes the Safety Task, Control of Rated Power and Rotor Speed Task and Durability Task. As the goal of the controls system is to consistently perform under all tasks, it is important to consider what actions are necessary to take during each state to produce the desired output, and what input triggers will transition between each state. The microcontroller is Arduino Uno, which acts as the brain of the system. In order to track the state of the system, a sensing system is needed to provide input signals into the microcontroller. Current and RPM sensors are selected based on the range, accuracy, resolution, supply voltage, reliability, and its compatibility with the chosen microcontroller. RPM is tracked using an IR sensor that detects black painted rotor that absorbs the infrared light emitted. A shunt resistor current sensor module is used to sense current signals with 1VDC/Amp resolution. To sense the voltage, voltage dividers are configured with high resistor values to minimize the power consumed and with a ratio 1:10 resistance to ensure the input into the Arduino Uno does not exceed 5VDC input limit. The power is controlled by dissipating power through large power resistors for braking and the load.

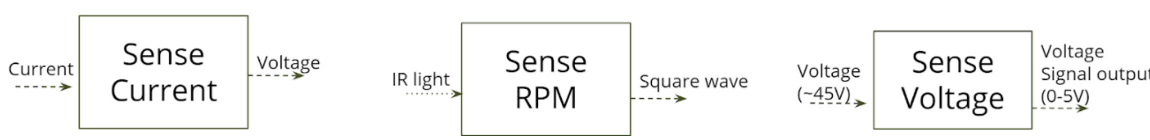

Figure 12. Input/output Block Diagram

The flowcharts illustrate the logic of the program, seen in figures 2 & 3 of the appendix. On the turbine, the control system monitors and controls the performance of the turbine through sensing and processing the voltage, current, and RPM. Arduino Uno which processes the voltage output, current output, and RPM. Feedback loop is used to continuous adjust the load and brake.

6.1 Electrical Brake

The ability for the system to brake is critical for the turbine's safety. An automatic speed control strategy is designed using Pulse Width Modulations (PWM) and MOSFETs, known as an electrodynamic braking system. This is achieved by shorting the generator on the DC side. The Arduino varies the applied brakes by varying the duty cycle as needed. The Arduino is an 8-bit AVR microcontroller where 0 V at the gate of the NMOS input keeps the MOSFET completely off and 5V gate input turns the MOSFET completely on. The functionality of the system is improved by selecting a Logic Level Power MOSFET. Considering the MOSFET compatibility with the Arduino, gate input 5 V, and lower threshold voltage, the IRF530 N-Channel was implemented into the system.

The system is designed to ensure that the rated RPM and power does not exceed the desired set points. If the turbine is over-producing power or over-spinning, the system must slow down or shut down for the safety of the turbine and protection of the electrical components. This is achieved using the electrodynamic braking. Following the past year's design, an improvement of the braking circuit is designed by paralleling three MOSFETs and power resistors to handle more power; therefore, withstand more stressful conditions.

Braking also plays a critical role in the safety task when the load is disconnected or when commanded by the judges to come to a stop (10% of the rated rotor speed). To achieve this task, the mechanical brakes are actuated first to slow down the blades considerably then followed by the electrodynamic brakes to smoothly and precisely reach below the 10% rate rotor speed while still producing above 6VDC to keep the Arduino Uno on and powering the motor.

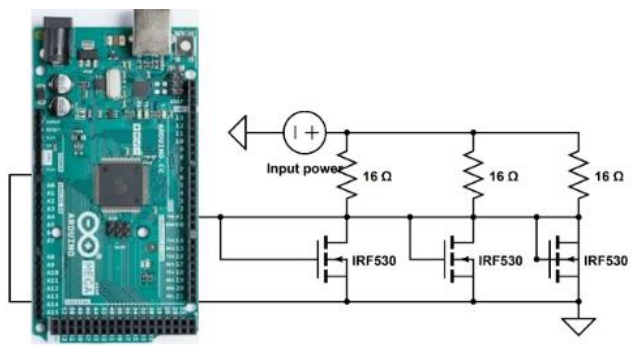

Figure 13. Braking system

6.2 Mechanical Brake 1: Pitch

From an understanding gained on attempting to implement an active pitch system last year, a huge push to incorporate a new and refurbished system was set out by the team. The initial design of the active pitch system used a helicopter pitch system which was outsourced and used an existing design. The weight of the material used led to an unintended moment of inertia on the shaft and ultimately restricted the blade movement of the turbine. It resulted in reduced power production, therefore, the design was rejected and replaced with stationary 3D printed blades fixed in the hub.

This year, the team was determined in creating a successful active pitch system to be incorporated with a motor; allowing for electrical control. For the prototyping phase, a 3D Simulated Model was designed and elaborated on provided in figure 14. The design utilized the concept of the helicopter pitch system worked on last year but additionally used machined aluminum parts press fit to linear and rotary bearings which allowed for an increase in performance of other components such as the blades, generator, and electrical system. The adaptations were machined out of aluminum due to its lightweight properties when compared to the stainless-steel material originally. This change allowed for a more lightweight and smaller design, thereby minimizing the associated weight that was problematic. Due to the precision and accuracy needed for the machining involved with the attachments, the issue of time arose in implementing the fully completed design. A final team decision led to rejection in the proposed design due to a time constraint in the integration phase with the full turbine as well as having enough testing trials to fully conclude if it would truly help with the control and associated power output.

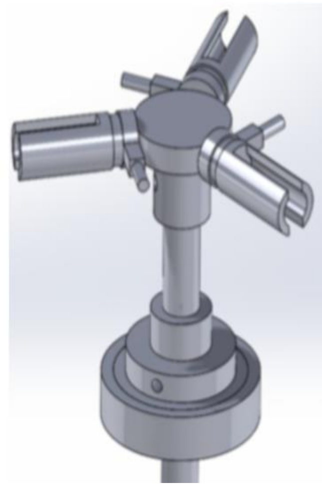

Figure 14. 3D Model of Active Pitch System

6.3 Mechanical Brake 2: Disc Clamp

The alternative braking to pitch system was a traditional mechanical disc clamp. The design is rather simple and easy to implement. A disc collar was machined to fit on to the drive shaft of the turbine. While installed, the disc could freely rotate between the clamp. The wire which is usually actuated by calipers will now be attached to a rotary wheel head on top of a servo motor. This servo motor will be mounted in a custom 3D printed housing on the base of the nacelle. The purpose of this is to provide support when actuated and ensure consistency when pulling the clamp. When turned on, the servo head will rotate clockwise, pulling the wire attached to the clamp. Thus, applying friction to the disc collar and slowing it down. The servo motor selected was chosen to have an appropriate torque output, draw minimal power, and have precision when executing the task. Precision is important since it allows the ability to have full or partial brakes during the safety task. Currently, the team is still testing this design and working towards finalizing its setup prior to the competition.

6.4 Maximum Power-Point Tracking

Maximum power point tracking is achieved through a feedback loop by varying the load and measuring the voltage output. To achieve maximum power point tracking, the load was first set at the cut-in load (the minimum load) then varied based on the voltage feedback. Through testing, it was seen that the maximum power was achieved when the generator was producing more than 40VDC. To ensure the output of the generator did not exceeded the 48VDC, 40VDC was chosen to be the set point. After cut-in, the voltage was checked and fixed at the minimum load until 40VDC was reached. If the voltage exceeded the set point, the load was increased. However, when the voltage was below the set point, the load was decreased. Once the rated power is reached or exceeded, the load was fixed at the rated load at 11 m/s wind speed. When the wind speed was above 11 m/s, the brakes were activated on the turbine side using the voltage feedback to maintain the setpoint of 40VDC. The turbine side is not involved until the power exceeds the rated voltage which is when the load on the load side of the PCC cannot hold the output of the generator below the set point. This point is not reached until the wind speed exceeds 11 m/s after which the load is fixed, and the turbine side electrodynamic brakes actuated to maintain the rated power and RPM.

7. RESULTINGS AND TESTING DATA

Following the 2018 competition the teams focus was to finalize the system design as early as possible to leave time for refinement. By end of January 2019, the turbine had been finalized and was ready for testing. Testing was coordinated in phases based on the testing tasks. These were rolled out according to the sequence of which each task is performed. Below in figure 15 is this year's power performance curve. This graph details the following three tasks; Cut-in, Power-curve, and Control Rated RPM and Power. All three tasks were performed with the full competition setup. This includes an Arduino Uno autonomously performing maximum power point tracking on our competition load and control system. Currently, this scores the maximum points needed for these three tasks.

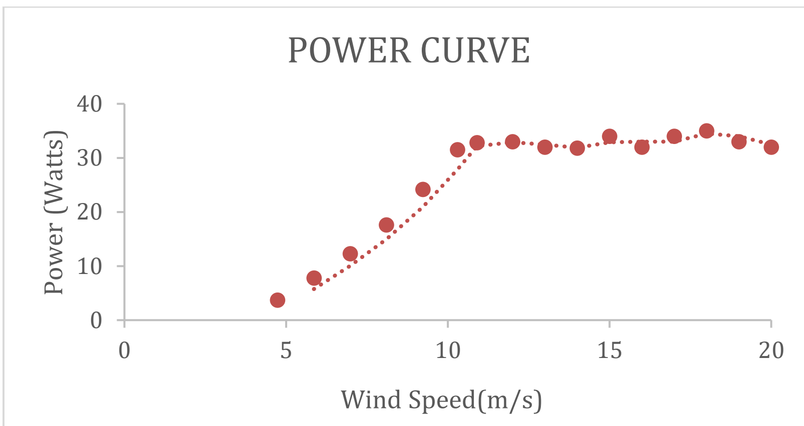

Figure 15. Power Curve

Throughout the semester the team learned how to refine and fine tune testing until we were able to achieve these results. This was possible by testing different spacing between the rotors, different blades, different magnets, and varying programming as necessary. From last year it was clear that the team needed to improve on signal smoothing, voltage spikes from the generator, and better understanding the trade-offs when designing for each task.

As for the safety and durability tasks there is still room for improvement. While tested at lower wind speeds, a servo motor can actuate disc brakes on an extruding component from the driveshaft. This servo accuracy allows for full and partial braking to take place. A decision before the competition will need to be made whether the disc brakes can slow the rpm to 10% of its max or if it must brake the turbine entirely during the safety task. Once safety is finalized, the durability will be tested the final week before the competition. The durability task has been placed with the lowest priority for testing since it is not required to compete. The team understands that as long as the turbine does not get disqualified that is okay to achieve zero points as an attempt for this task

8. CONCLUSION

In comparison on the performance between the year of 2017-2018 and 2018-2019, the JMU CWC team has significantly improved on the system integration of electrical and mechanical systems. The JMU team has learned from their mistakes and prepared to showcase the final product at the National Wind Technology Center in Boulder, Colorado. Although the participants of the 2018 and 2019 CWC events are now graduating, the team plans to document this learning experience and pass it onto the next competing team for the growth of JMU in the future competitions and as well as in the wind energy sector.

Acknowledgements

George Lovell, the JMU's Mechatronics Technician helped the team continuously throughout the past two years on assisting in the Circuit Laboratory and providing guidance on the topics of electrical codes and standards. Lovell's expertise placed the JMU CWC team to succeed by teaching hand-on skills and techniques required for soldering, electrical wiring, and proper organization of electronics.

Dr. Keith S. Holland, the capstone advisor of the CWC JMU’s engineering team, has consistently provided feedback, knowledge on the all areas of designing a small-scale turbine, including topics of mechanical and electrical design. Dr. Holland’s expertise has placed the CWC team to succeed by continuously mentoring each member to grow as an engineer throughout these past two years.

John Wild, Laboratory Manager in the JMU’s Engineering department, provided his expertise on 3D printing machine operations, welding of parts, and recommended design ideas.

Scott Padgett, the Lab Technician in the JMU’s Engineering department, provided us with any necessary technical advice.

Mark Showalter and Dr. Karim Altaii, the wind tunnel laboratory managers in the CISE department at JMU, provided us access to the wind tunnel and administered the team during all testing.

Mark Starnes, the head Machinist in the JMU’s Engineering department, assisted in fabrication of mechanical parts.

Braking is achieved through a concept known as electrodynamic braking by shorting the generator on the DC side of the power. The Arduino Mega sends pulse width modulated signals to the gate of a logic-level based MOSFET which shorts the generator producing a high back electromotive force. The Arduino varies the applied brakes by varying the duty

Appendix

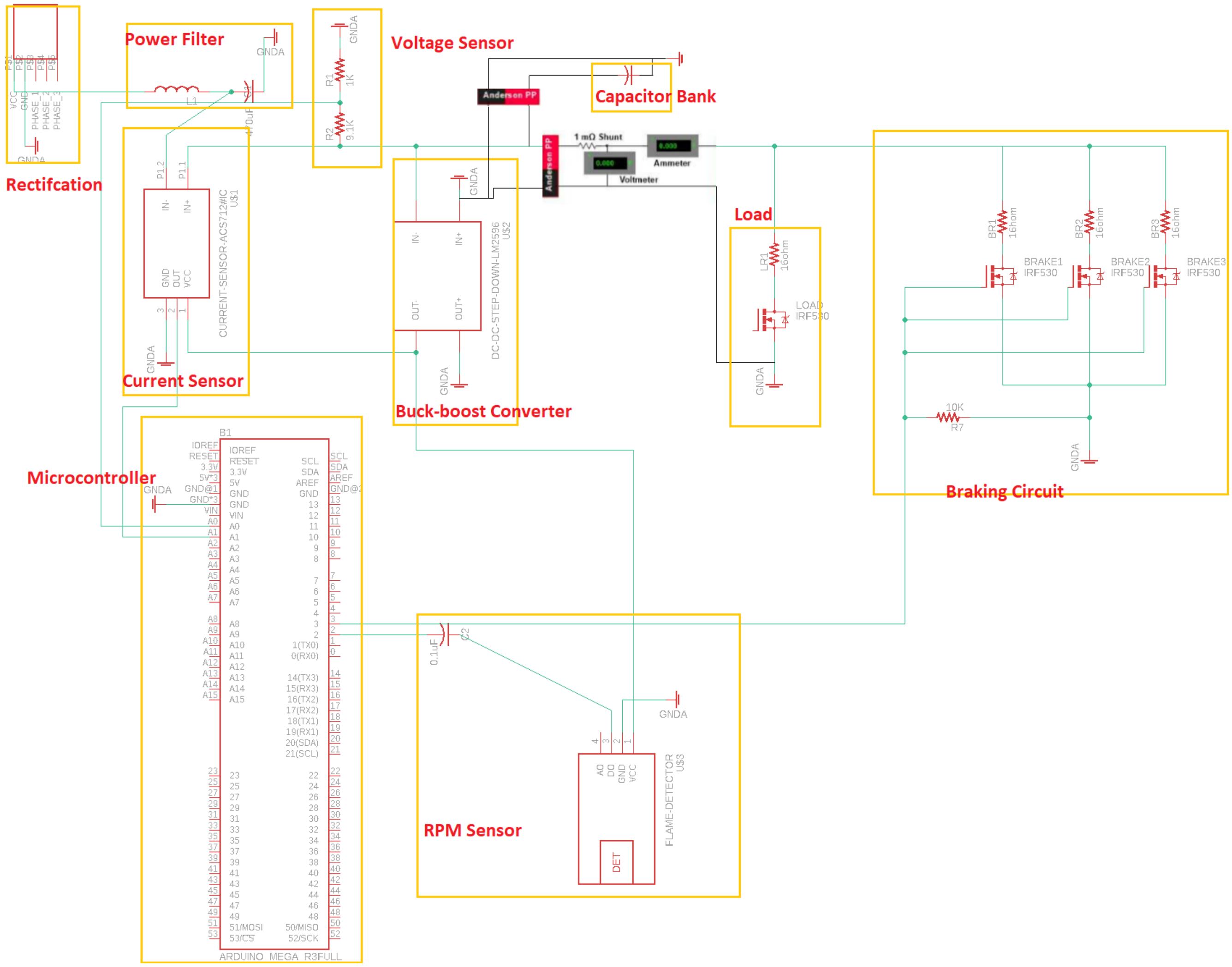

Figure 1. Electrical Schematic

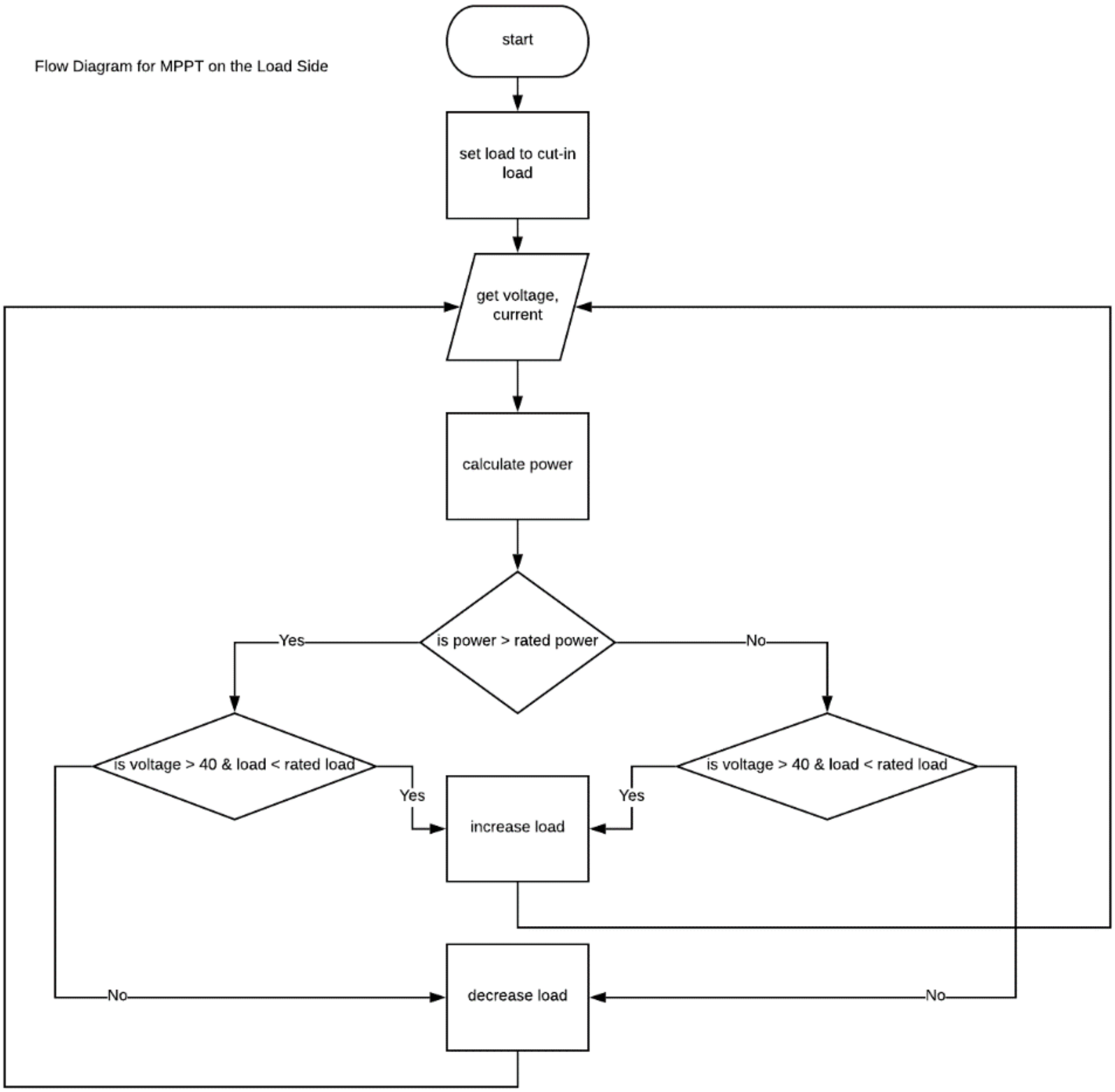

Figure 2. Flow Chart for the Load Side

Figure 3. Flow Chart for the Turbine Side