NAU Collegiate Wind Competition 2016 Tunnel Team

Background Research Report

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Contents

1 – Background

This section contains the information regarding the purpose and goals of the Collegiate Wind Competition Tunnel Team. The project overview contains the general introduction for the competition, the description of the competition requirements, and the details surrounding previous year's competition models.

1.1 – Introduction

The US Department of Energy's (DOE's) Collegiate Wind Competition (CWC) involves 12 colleges around the United States, and is designed to give students a better understanding of wind energy. The competition also gives students real-world experience in the design, construction, and testing of a wind turbine generator and related turbine components (e.g. turbine controls). These aspects are coupled with drafting a deployment and business plan of a larger scale turbine that mathematically corresponds to a proof-of-concept scale model. Employers attending the competition will be interested in the experience attained by students and competition attendees.

1.2 – Project description

The purpose of the Tunnel Team involves the design a highly competitive wind turbine, which fulfils the requirements illustrated in Section 2. The turbine will be taken to competition in New Orleans and tested against turbines designed by other colleges. The Tunnel Team will follow the guidelines that are given by the Department of Energy in order to be eligible to compete in the competition. The turbine will be built to specific size, design, and safety requirements and care will be ~~take~~taken to create a turbine that has a competitive advantage when compared to the turbines from previous years at NAU.

1.3 – Previous Competition Turbines

The NAU wind turbine Tunnel Team has the ability to look back at the turbines designed from the 2014 and 2015 competitions. By reviewing methods used previously the current team can learn from mistakes made and improve on some of the previous design ideas. Along with having the previous turbines to glean information from, the team also is in contact with participants and clients from previous years.

2 – Requirements

This section gives a more in depth analysis of the requirements for the CWC, based on the rules and regulations issued by the DOE. The input from the faculty mentors has assisted in deriving the preliminary interpretation of the engineering and customer requirements

2.1 – Introduction

This section entails guidelines that have been given by the Department of Energy and our clients, David Willy and Karin Wadsack. These include aspects related to turbine construction, electrical design and organizational matters. The team has created a house of qualities that rates the importance of each of these customer requirements related to the validity in the project.

2.2 – Customer Requirements

The customer requirements were derived from the rules and regulations document that was provided by the Department of Energy. These requirements are discussed in this section ~~and have~~and have been given a rating based on each requirements level of importance. The weightings scale for these requirements is based on a total value of 250 points.

The highest rated customer requirement in the house of quality is Power Curve Performance with a rating of 40/250. With this requirement the team must design a turbine that can produce its optimal power within the range of 5 m/s to 11 m/s. The judges will be concerned if the team is not able to create power adequately or if the speed required to create the power is above- this range.

In order to control the power and speed for the wind turbine a requirement of 25/250 for each has been determined. It is required that the turbine be able to slow down itself when wind speeds higher than 11 m/s are present. The ideal case for grading will be to design the turbine so that it will be at optimal output at 11 m/s so that we can control our power and speed to the DOE's requested specification.

The load system supplied was rated at 25/250 points. The high point rating of this load was put in place because the DOE will be grading the load on a level of safety and creativity. By successfully achieving both goals, the design of the load would give the team a major advantage at competition.

Throughout the project, wiring and electrical connections will be essential to ensuring a successful test, safe operation, and clean wiring design. Due to these aspects the wiring and connections requirement were given a 25/250 rating.

The cut-in wind speed requirement is rated at a 25/250 so that the team will put particular emphasis on designing a turbine that can begin producing power at the lowest wind speed possible. If cut-in wind speed begins after 5 m/s then points will be deducted from the team's score.

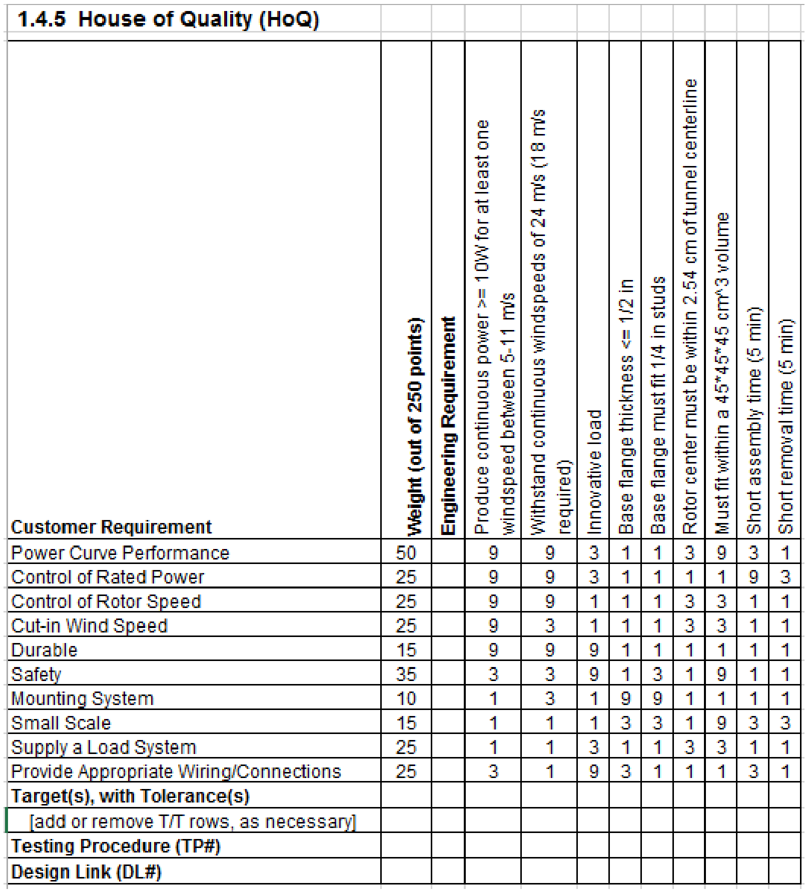
The turbine is required to be built durable enough to withstand testing in the tunnel, transportation and multiple setups. Although this has some importance, the team rated this requirement at 15/250. Along with durability the safety of the turbine will need to be considered. The aspect of safety is rated at 45/250 due to the need for a sound design. If the turbine proves to be hazardous then it will not be able to compete. An emergency braking system is required to ensure that the turbine will stop completely if an issue arises. The turbine must also be stopped by braking if the turbine experiences a loss-.

If there are unseen hazards or a faulty braking system then injury or property damage could result.
The mounting system for the turbine was specified by the Department of energy. Although it seems to be a simple issue, having mounting hardware not properly aligned with the DOE's requirement will require last minute modifications that could delay testing and potentially reduce the overall score. The mounting system has a customer requirement rating of 10/250.

The scale of the turbine is required to meet all parameters that are currently in place for testing purposes. Care will be placed in the future months to ensure that any revisions of scale requirements are met and properly adapted to the controls system requirements.

2.3 – House of Quality (QFD)

The following house of quality is laid out to prioritize the customer requirements when connected to each of the criterion listed along the top of the chart. It will be used for the team to properly characterize what level of importance each aspect of the design pertains to areas of the customer requirements. The preliminary House of Quality can be seen in Figure 1.



1.4.5 House of Quality (HoQ)

Customer Requirement	**Weight (out of 250 points)**	**Engineering Requirement**	Produce continuous power >= 10W for at least one windspeed between 5-11 m/s	Withstand continuous windspeeds of 24 m/s (18 m/s required)	Innovative load	Base flange thickness <= 1/2 in	Base flange must fit 1/4 in studs	Rotor center must be within 2.54 cm of tunnel centerline	Must fit within a 45*45*45 cm^3 volume	Short assembly time (5 min)	Short removal time (5 min)
Power Curve Performance	50		9	9	3	1	1	3	9	3	1
Control of Rated Power	25		9	9	3	1	1	1	1	9	3
Control of Rotor Speed	25		9	9	1	1	1	3	3	1	1
Cut-in Wind Speed	25		9	3	1	1	1	3	3	1	1
Durable	15		9	9	9	1	1	1	1	1	1
Safety	35		3	3	9	1	3	1	9	1	1
Mounting System	10		1	3	1	9	9	1	1	1	1
Small Scale	15		1	1	1	3	3	1	9	3	3
Supply a Load System	25		1	1	3	1	1	3	3	1	1
Provide Appropriate Wiring/Connections	25		3	1	9	3	1	1	1	3	1
Target(s), with Tolerance(s)											
[add or remove T/T rows, as necessary]											
Testing Procedure (TP#)											
Design Link (DL#)											

Figure 1: Preliminary House of Quality

3 – Subsystem Research and Testing Procedures

The Tunnel Team has broken the wind turbine design down to seven subsystems: blade, structure, generator, controls, software, power electronics, and load. Each subsystem will be designed separately while also ensuring that each component is compatible with the rest of the system.

3.1 – Blade

The blades of a wind turbine use lift forces created by a pressure gradient to rotate. This pressure gradient is created by the shape of the airfoil which accelerates wind on top of the blade causing a low pressure zone while the air under the blade travels at the original speed creating a high pressure zone. The resulting lift force causes the blades of the wind turbine to rotate.

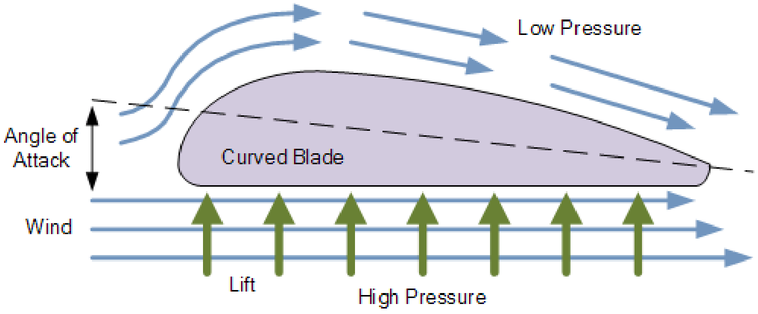


Figure 2: Mechanics of a Wind Turbine Blade [1]

3.1.1 – Market Research

As the competition rules state, the rotor must have a diameter no larger than 45cm [2]. The blades should begin rotating by 5m/s in order to begin power production. There are many different airfoil design being used in the market, with each one having its own range of cut-in speeds and optimum running speeds.

3.1.1.1 – Airfoil

Noticeably the biggest part of designing a blade is design the airfoil (the geometrical shape of the blade). This is done using Blade element momentum theory (BEM) along with the Betz limit which is the theoretical maximum efficiency an airfoil could possibly achieve. There are many airfoils designs being used in industry right now and each one had unique properties that allow for producing power at low speeds or at high speeds.

3.1.1.2– Blade Material

Blade design is complex since the blade must be lightweight but also have high strength and high bending stiffness. This is because the top half of the blade experiences compression-compression loading in high winds, while the bottom half experiences tension-tension loading. So the blade must be made of a material that has a high compression and fatigue strength [3].

3.1.1.2.1 – Carbon Fiber

Carbon fiber is the ideal material to manufacture the blades out of as carbon fiber has- high tensile and compressive strengths and is light-weight. The biggest problem is carbon fiber is rather expensive and is only used in high stress areas of large scale turbines such as the spar. Other than price, possible challenges for carbon fiber is that the strength is compromised if the fiber alignment is off at all and if the resin does not completely penetrate the fiber due to the complex shape [3].

3.1.1.2.2– E-Glass

E-glass is the most common fiber glass used to construct wind turbine blades. Being heavier and weaker than carbon fiber E-glass is not the optimum material to make wind turbines blades but it is much cheaper than carbon fiber [3].

3.1.1.2.3 – Plastics

Plastic is not an ideal material for large scale wind turbine blades, but offer an alternative to fiber composites as plastic is easily accessible and has a low cost. Analysis would need to be done to ensure that the plastic blade can withstand the forces and stresses without significant deformation.

3.1.1.3 – Dielectric Polymers

Dielectric polymers are polymers that generate power from be deformed. Although dielectric polymers have been used in the past to generate power or they were used as an actuator, our research is to use them as a sensor in the blade that would allow wind turbine operators to see stress in the blades by measuring the electrical output. This would give wind turbine operators another tool to monitor the condition of the wind turbines components [4].

3.2 – Structure

The Tower can be made of several different materials and designs. Some possible options are as follows. A visual representation of the materials is provided in Figure 3.

3.2.1 – Pipe

The benefits of using a pipe for the central support are, it is strong, cheap, durable, and has a simple fabrication process. Regular Mild steel pipe is abundant at many hardware stores and is easily welded to the baseplate and Nacelle/ Main Frame.

3.2.2 – Square/ Rectangular tube

The benefit of square or rectangular tube is that it has a high bending moment making it very structurally sound. The shape allows for easy fabrication and mounting of components to the tower.

3.2.3 – Carbon fiber airfoil

This tower design creates less turbulent airflow that could possibly interfere with the function of the turbine blades. Also an airfoil shape will most likely produce lower drag forces from the wind acting on the tower. The drawback of this design is that it could involve difficult and possibly expensive molding processes that could create complications in structure. Also material choices that could make an airfoil structurally sound could prove to be expensive.

3.2.4 – Market Research

The DOE provided some specific structural requirements and needs for the wind competition. The structure must be created to hold the rotor within 2.54 cm from the center of the wind tunnel. The Base plate must meet specified dimensions shown in Figure 4 in order to fit on the testing stand. Also, the rotor dimensions cannot exceed 45 cm in length width or height [3].

3.2.4.1 – Nacelle

The mainframe must be a narrow design so that it does not interfere with the downwind flow from the rotors. The material for the mainframe will most likely be a steel box to hold the ~~the~~ generator and electrical components. The mainframe could also be 3D printed so that it can have an aerodynamic contour.

The “Yaw” which is the connection between the mainframe and the tower will be fixed. This will eliminate the need for the turbine to have a tail piece. The Hub will most likely be made of aluminum and must be milled to be as balanced as possible to avoid vibrations at high RPMs.

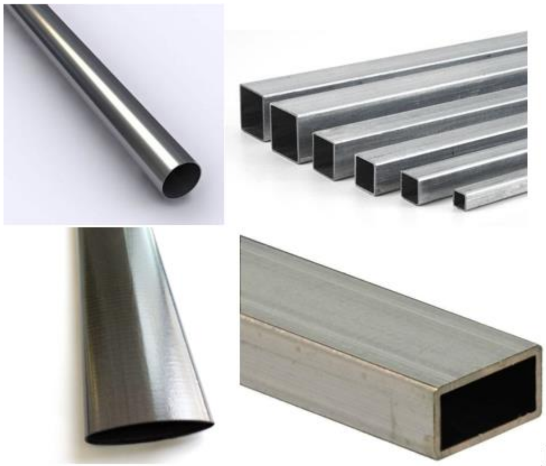


Figure 3: Steel Pipe, Square and Rectangular Tubing, and a Carbon Fiber Airfoil

3.2.4.2 – Mount

The base plate can be made from many different materials and thicknesses, however due to the simplicity of the part quarter inch A36 Mild steel is recommended to keep price down and maintain strength at the same time.

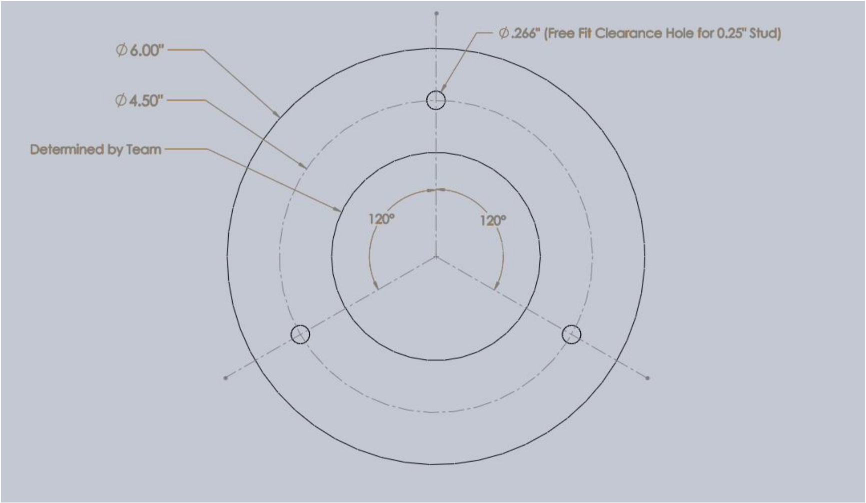


Figure 4: Base Plate Dimension Requirements [4]

The Tower, Base, Mainframe, Rotor, and Hub can all be original designs provided they are within the Customer requirements listed above.

3.2.5 – Benchmark Testing

The testing of the structure is broken into three separate pieces, nacelle, tower, and mounting plate. Each section of the structure has different requirements in strength, durability and rigidity all potentially requiring different material. To get an initial force analysis of all the parts of the structure forces of a general area and point forces will be used to determine an appropriate material. After a material has been selected the computer program Ansys will perform a finite element analysis (FEA) on each part to determine any potential design weakness.

3.2.5.1 – Nacelle

The nacelle is located at the top of the tower and houses the generator and all other electronics designed to be close to the generator. The nacelle provides a mounting bracket for the motor and must attach to the tower. A Nacelle can house a yaw if the design requires, it is still undetermined if a yaw will be necessary given the test conditions. For preliminary testing -a point load will be applied at the mounting brackets for the generator. Then a full FEA on the nacelle, this will allow the decision of the best strength to cost and weight ratio.

3.2.5.2 – Tower

Depending on the final design choice of the tower it will dictate the necessary test parameters. If a straight pipe and square/rectangular tubing design is chosen, which the last two previous years have done then only basic testing is needed before material selection. This is because most materials available will be provide more than sufficient strength for the turbine a FEA will be performed to make sure all forces are within tolerance as well. If an airfoil is chosen for the tower a full finite element analysis will need to be completed before material selection. With an airfoil the forces will be unevenly dispersed and have higher stress concentration factors, but will provide less downwind flow interruption.

3.2.5.3 – Mounting Plate

The mounting plate has very little design room the Department of Energy has given measurement and material specifications. The mounting plate cannot be thicker than half an inch and be able to withstand a ten newton-meter force. In addition the mounting plate must have 3 quarter inch holes spaced at 120 degrees apart spanning a diameter of four and a half inches. Due to the success of the previous years' mounting plate a very similar design will be used.

3.3 – Generator

The generator of the turbine utilizes properties of magnetic induction to produce an electrical current. Due to the requirements of the competition, which restrict overall size of the turbine, the generators being researched were manufactured for small model applications. The market research shows the differences in motors designed for model remote controlled airplanes, and model electric trains.

3.3.1 – Market Research

Small scale motor/generators are used for miniature, remote controlled, battery powered models. Model airplanes and model electric trains were used for research purposes to meet the size restrictions imposed by the Collegiate Wind Competition rules and regulations. Another aspect of generator design was to determine the type of electrical power that needed to be generated. Consistency with current practices in industry limits this to the following: three-phase alternating current (3-A/C), single phase alternating current (A/C), or using direct current (D/C). There are advantages to all forms of power generation; however, which type is used is determined by the circumstances of the power transmission. For maximum output of the generator for the turbine, 3-A/C will produce the most power per RPM compared to the other two commonly used power types [6].

Cogging torque is another aspect to be considered in selection of the generator. Cogging torque is a force that needs to be overcome before the generator can start spinning and producing power. This force is caused by the interaction between the generator magnets, and the generator coils. There are options that can be considered to reduce the cogging torque. Lowering this torque can increase the cost of the generator, reduce its maximum power output, or increase the generator size to be outside the scope of this project.

The state of the art technology includes changing the electrical and magnetic properties of the motor to increase efficiency. By removing the spaces between the permanent magnets on the rotor, the cogging torque is lowered, but this process is expensive and can lower the overall power output of the generator. Using an air-cored motor can increase power generation by increasing heat dissipation within the generator coils, which allows for a higher RPM to be achieved by the generator before failure occurs. Using a brushless motor removes wearing components that have been standard to motors/generators since their conception. A brushless motor rotates a permanent magnet rotor by switching the polarities of electromagnets within the stator.

3.3.3 – Benchmark Testing

The faculty sponsor for this project is requiring that the generators from the previous competition turbines will need to be tested prior to testing additional generator options. Currently the test load is still under construction, and testing has been scheduled for a future date. The testing procedure includes a dynamometer that will drive the generator, allowing for the testing of output power at various speeds. This information will provide the data necessary to generate a plot for the power curve, which will give a baseline to meet or exceed for future motors to be tested.

3.4 – Controls

Controls for the turbine will consist of various pieces of hardware and software that will work together to control important parameters, such as turbine RPM, and power output. Many components exist for use in different subsystems of the control system, including different electrical/electronic (transistors, microcontrollers, relays) and mechanical (disk brakes) devices. Microcontrollers, one of the electronic types of components, need software to carry-out their control function.

3.4.1 – Market Research

Research for controls currently consists of a review of the appropriate literature, as well as shared information acquired from knowledgeable faculty, team members, and students. More research needs to be done on more specific control methods; new research also needs to substantiate knowledge supplied by individuals.

3.4.1.1 – Wind Energy Conversion System

One way to describe wind turbine controls involves a system described as a Wind Energy Conversion System (WECS). One of the 4 subsystems of a WECS is a Pitch Servo, which contains a hydraulic or electromechanical device that rotates the turbine blades side to side, based on wind direction. Controls are also needed on the power generator unit subsystem, although the specific controls are not specified. See Figure 5 for more description [6].

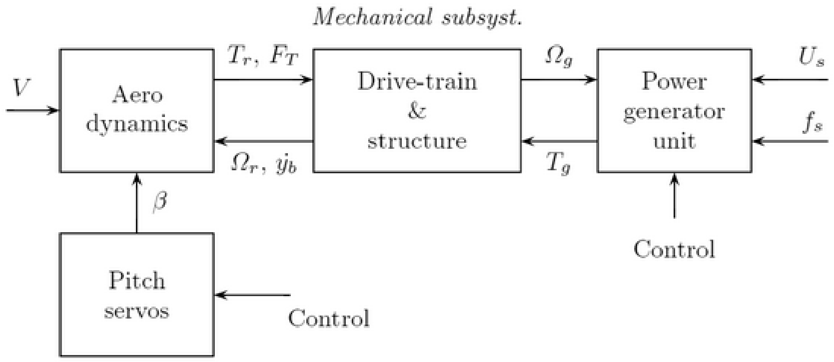


Figure 5: Block Diagram of the Subsystem Levels of a Variable Speed and Pitch WECS [7]

3.4.2.2 – Adjustable Speed Drives

Devices called Adjustable Speed Drives (ASD) can be used to control induction motors. Although induction motors are not equivalent to generators, they are relevant in their inverse nature: motors use principles such as induction to produce mechanical work, while generators convert mechanical work into electricity via principles like induction. Microcomputers, microcontrollers, and digital signal processors (DSPs) can be used to control ASDs. ASDs can implement methods that include direct field orientation (DFO), indirect field orientation (IFO), indirect rotor flux orientation, and stator flux orientation, as mechanisms of operation [8].

3.4.2.3 – Other Important Resources

Relevant topics include generator-side control, power control, and logic and safety function. The generator-side control system implements changes on the AC/DC converter, and receives signals from the generator itself. Both power control, and logic and safety function implement changes on the generator-side control system, and receive input from a gearbox attached to the generator and turbine.

Brake systems must be used to stop the turbine blades from spinning (and producing power) in the event of a system disconnect, or on command (see Design & Customer Requirements). Possible brake systems include the following: an AC break placed between turbine and AC/DC converter, a DC break placed between AC/DC converter, and DC/DC converter, and a mechanical break placed in/around turbine. AC and DC brake systems involve shorting +, - and GND leads.

A phenomenon known as Proportional Integral Derivative (PID) can be used to monitor and decrease turbine RPM. One key danger that lies within decreasing turbine RPM is the generation of RPM fluctuations that result from imperfect control systems. PID creates a steady RPM by constricting RPM into two counteracting integral and derivative curves. The integral curve is concave-up, while the derivative curve is concave-down.

3.4.3 – Benchmark Testing

The CWC Rules and Requirements document outlines some important metrics to be taken into consideration when testing generator controls. The metrics are listed as follows:

1.) Turbine must be able to shut down (within 10 seconds) on command (by a provided switch), and when disconnected from the point of common coupling [9].

2.) Turbine must keep rpm and power below rpm and power determined/produced at 11 m/s wind speed.

Microcontrollers, relays, MOSFETs (transistors), and other hardware will be needed for benchmark testing. The specific microcontroller and other hardware are yet to be determined.

Previous CWC teams, like NAU and Kansas State University's (KSU) 2014 team have used transistors including BJTs and MOSFETs in their brake systems [10]. This team's brake system involved the same mechanism of shorting +, -, and GND leads described in section 3.4.2.3, and was designed to automatically switch on in the event of power loss. The 2014 NAU/KSU team also employed an Arduino microcontroller to implement controls. In order to effectively test the generator controls, each piece of hardware (transistors, microcontrollers), and software (code programmed onto the microcontroller) must work as expected from the CWC rules and regulations.

3.5 – Software

The purpose of the software team is to consolidate with both the controls team as well as power electronics team in order to designs a controls system that meshes well with the power electronics components chosen. Furthermore, the master code for the system will be compiled by the software team using the individual algorithms composed by the controls team.

3.5.1 – Market Research

Two main choices the team is currently debating on for a microcontroller is either the Arduino or the MSP430. Both components have their pros and cons and will need to be weighted accordingly for what best fits the overall needs.

Looking at the Arduino it has been shown to handle complex algorithms because of the large amount of ram that is present on the Arduino board. However, one major drawback to the Arduino is that it has a large power draw. When dealing with a low power system like the teams CWC wind turbine, unnecessary power draw could cause the system to underperform what is to be expected.

Looking at the MSP430, it has a smaller onboard ram than the Arduino; however, it has been shown to work well in many areas such as:

- Remote control
- Digital motor control
- Measurement of Voltage, Current, Apparent Power, and Reactive Power
- Robotics
- Solar applications

From this, the MSP430 is capable of handling complex algorithms, more so than what will be used within this project. Alongside that, the MSP430 as a much lower current active draw at 300µA [11] vs the Arduino idle current draw of 50mA [11]. The control boards for both the MSP 430 and the Arduino can be seen in Figures 6 and 7.

Figure 6: MSP430 ~~Launchpad[~~Launchpad [12]

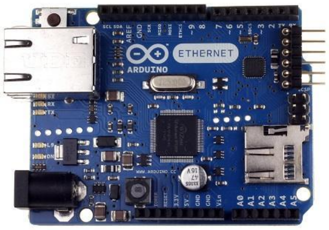


Figure 7: Arduino Control Board[13]

3.5.2 – Benchmark Testing

The testing for the software aspect will be to team up with both the controls team as well as the power electronics team in an attempt to make sure that all pieces designed by the control team is compatible with what the power electronics team is wanting to do. There are four main controls aspect that we need to take into consideration (start point, cut in, rated power, and brake point); each control points will have to be individually tested to make sure they work properly alongside the power electronics selected components. Finally, a master code will need to be written which is composed of all the individual control parts. The final testing will be with the master code and the final construct of the power electronics team.

3.6 – Power Electronics

Power Electronics are the circuits between the generator and load, to put it simply. The main topology of these parts follows as such: Generator feeds into a Rectifier, Rectifier feeds into a Power Converter, and Power Converter feeds into the Load [12]. Rectifiers are circuits that convert AC power to DC power, and power converters are DC-to-DC converters that adjust voltage, and thus power, as current flows through them. There may also be a DC-to-AC converter between the power converter and the load, if the load design is not DC-based. Figure 8 shows a visual breakdown of the Power Electronics structure.

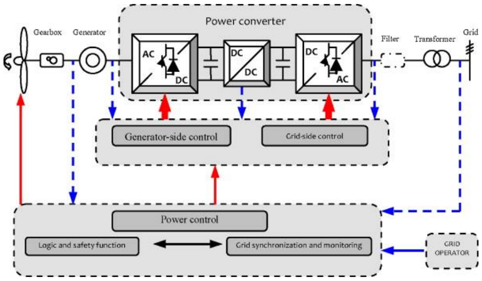


Figure 8: Power Electronics Flow Chart [13]

3.6.1 – Market Research

For market research, the Power Electronics Sub-team decided what qualities of design are important to the team’s goals. After performing a literature survey, the team found three important qualities: Power Curve Performance, Safety, and Provide Appropriate Wiring/Connections.

The power curve is the graph of power vs wind speed, and is made up of four regions. Region 1 is before any power is generated, region 2 is where power is being generated below the Rated Power of the system, region 3 is the level at which the power must be adjusted to match Rated Power, and region 4 is where the system is forced to brake [15]. This is where most of the Tunnel Team’s points will be made at the competition, so here is where the focus of the Power Electronics Sub-team will work. Figure 9 shows the visual representation of the power curve breakdown.

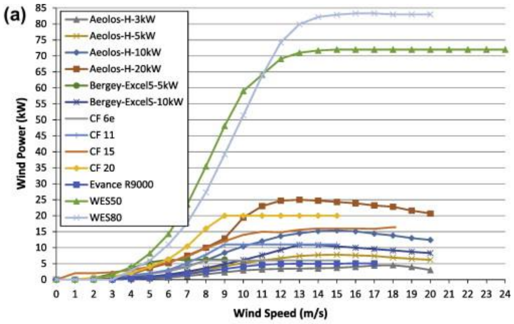


Figure 9: Power Curve for Various Wind Generators by Speed [14]

There are two main safety concerns: the insulation of the electrical components, and the braking capabilities of the system. Two brakes are necessary for the Tunnel Team's design: a button-activated brake, and a brake to engage in loss of load. These are both in addition to the brakes used for Power Curve Performance. The possibilities for the barking systems are: a mechanical brake, an AC brake, or a DC brake [15]. The AC brake uses three switches to divert current into a resistive load, which will provide torque to the generator and slow it down. The DC brake uses only one switch to do so, but does this after the rectifier, which lessens the effect.

By using quality parts to cut down on Power loss ($P_{loss} = I^2R$), the power curve performance of the turbine can be improved. Spending time using simulation software and practicing with physical circuits, will help perfect the design parameters required for the competition

3.6.2 – Benchmark Testing

The Power Electronics Sub-team performed analysis on previous years' projects, both those in which Northern Arizona University had a hand and those by other colleges. By analyzing their designs, numerous ideas and benchmarks became apparent to the sub-team. The differences between the various power converter designs proved useful in narrowing down the possibilities for further simulation, and the braking systems in previous years will prove useful when designing and testing the sub-team's own design.

In addition, the Power Electronics Sub-team determined the necessity of working together with the Software and Controls sub-teams from previous designs. Algorithms were the primary focus of this benchmarking, as designing a proper algorithm to read data from the power electronics and then perform actions on the rest of the turbine is a major portion of the technical design reports submitted by previous teams.

3.7 – Load

Our load will need to be large enough to store all power generated by our wind turbine. The design of the load will depend on the amount of power the wind turbine can generate.

3.7.1 – Market Research

All wind turbines are designed to run while connected to an electric load, (either a battery bank or an electrical grid) these are called dump loads. If a wind turbine is spinning without an attached load it runs the risk of self-destructing, this is because the turbine is doing no work and is spinning as fast as the wind can make it which could lead to catastrophic failure. For our project we'll be using a battery bank as our dump load since the wind turbine will be on a small scale.

Wind turbines also utilize something called a diversion load. When the turbine fully charges the battery bank it needs to stop charging it in order to avoid overcharging the battery. But the wind turbine still needs to be hooked up to a load. This is where the diversion load comes in. More specifically, it uses a diversion load charge controller which is a sensor switch that monitors the voltage of the battery bank. When the battery bank reaches its maximum voltage the sensor switch disconnects the wind turbine from the battery bank and connects it instead to the diversion load. Once the diversion load charge controller senses a drop in voltage in the battery bank it reconnects the turbine to it.

This presents two options for the load design that hinge on the amount of power our load can hold. If the load cannot store enough power to serve our purposes then it will require a diversion load and a diversion load charge sensor. However, if the load is large enough then it will eliminate the need for either the diversion load or the sensor switch.

3.7.2 – Benchmark Testing

To see if your load is going to consume the power for the turbine we are going to use a dynamometer. A dynamometer can measure force, power, or speed- to see if we need more power or how much we can handle. Dynamometers come in all shapes and sizes. How the dynamometer works is by soaking up or absorbing the power that the engine/motor produces.

4 – Budget and Schedule

The CWC 2016 team starting funds are $1500 a portion of these funds were provided by the Department of Energy the rest was contributed by private donors. The majority of the funds will be going towards traveling to the competition which will require more donations from private parties. Below is a cost prediction for production of the scale model of the turbine based on the costs from last year. This budget is not all inclusive it also does not account for possibility of donations from the various companies the CWC 2016 team is working with. Table 1 shows the anticipated cost breakdown.

Table 1: Cost Project for CWC 2016 Tunnel Team

Parts	Materials	Quantity	Cost ($)
Mainframe	Steel	1	15
Generator	Aluminum	1	25
Slip Ring	Plastic	1	25
Rotor	Aluminum Alloy	1	10
Hub	Aluminum Alloy	1	30
Ball Bearing	Metric Steel	2	50
Tower	1018 Steel	1	80
Blades	Polycarbonate	3	50
Retaining Ring	Black-Finish Steel	10	5
Nose Cone	Aluminum Alloy	1	20

Base	1018 Steel	1	20
		total	330

Currently, the schedule is still being finalized, preliminarily the dates included for completion of tasks and milestones are directly related to the due dates for the DoE competition and the deliverables for the ME476C capstone class. The final schedule will be completed no later than the 16th of October 2015.

5 – Conclusion

The overview of the competition requirements derived from the DOE's rules and regulations have been explained in detail that will assist with the preliminary design of the small scale build. Using these requirements will allow for the Tunnel Team to be able to produce a competitive turbine for the competition in the spring of 2016. By utilizing the different aspects of the build, research on state of the art technology and looking at the previous builds, the final product will be able to meet the requirements laid down by the competition.

By using the House of Quality to ensure our engineering requirements meet our customer needs, the process for further design and research will be more efficient. Using the research already compiled, with the ability to break down and analyze the previous competition builds will prevent costly errors during the design and prototype process.

The budget and scheduling are preliminary, with updated versions to be released as needed. This does cause a minor setback, however the Tunnel Team will be back on schedule no later than the 16th of October 2015.

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