NAU 2018 Collegiate Wind Competition

Preliminary Report

Test Team A
Kory Joe
Devon Hardy
Aaron DeLuca
Evan Heiland
Qian Zhao
Soud Alsahli

2017-2018

Project Sponsor: The U.S. Department of Energy (NREL) & The National Renewable Energy Laboratory (NREL)

Faculty Advisor: Dr. David Willy, Dr. Venkata Yaramasu, Dr. Tom Acker, Dr. Karin Wadsack

Instructor: Dr. Sarah Oman

DISCLAIMER

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

1 BACKGROUND

1.1 Introduction

This project goal is to build a wind turbine that will compete in the Collegiate Wind Competition (CWC), an event that is sponsored by the U.S. Department of Energy (DOE) and National Renewable Energy Laboratory (NREL). Collegiate teams from around America compete against one another in three competition challenges. The competition challenges listed in the CWC 2018 Rules and Requirements include building:

1. A research supported market business plan and a conceptual-level technical development design for a marketable wind power system.
2. A safe and reliably operating mechanical, electrical, and aerodynamic wind turbine and load design for testing in an on-site wind tunnel.
3. A constant voltage and competition-provided variable-resistance load electrical control system that can maintain during the durability portion of the turbine testing, utilizing while utilizing a competition-provided storage element to balance source and load energy.

The NAU CWC 2018 team is fully responsible for constructing our own wind turbine and providing our own transportation to and from the competition. The overall NAU team has been split up into three different teams: the Market Team, Test Team A, and Test Team B. Together the two test teams will design and construct a working turbine that fits into a 45cm by 45cm by 45cm cube [1]. This report is based on the components that Test Team A is responsible for designing. The components are: the blades, drive train, generator, DC-DC generator, and PCB Board. Therefore, the goal of the overall project relevant to this report is to design and construct certain wind turbine components.

This project provides hands on work experience that is similar to the wind energy industry work. Wind power at its current rate is "projected to double by 2020 and again in 2030," which means that there is a growing number of work opportunities within the field [2]. This project is designed to build the experience which students will need to fill the expanding job force within the wind energy industry.

Note that for the following sections, different students worked on their assigned sections. The work division is based on the components each student leads. Devon leads the work on the blades with help from Soud. Soud leads the work on the drivetrain with help from Kory.

1.2 Project Description

According to the project description on the DOE CWC website [1]:

> *The 2018 Collegiate Wind Competition will be held at American Wind Energy Association WINDPOWER in Chicago, Illinois, from May 8–10. Competing teams will design and build a model wind turbine based on market research and siting considerations, develop a business plan to market the products, and* ***test the turbines against a set of rigorous performance criteria*** *judged by a panel of wind industry leaders.*
>
> *The Collegiate Wind Competition challenges undergraduate students to design a wind turbine based on market research, develop a business plan to market the product,* ***build and test the turbine against set requirements****, and demonstrate knowledge of opportunities related to wind farm siting.*
>
> *Teams participating in the 2018 Collegiate Wind Competition will be expected to research and design a turbine for a grid scenario with a high contribution of renewables.* ***The turbine should be able to operate in islanded mode****.*

Note that the bolded sections are what is relevant to Test Team A. We will be building a prototype turbine for testing within a wind tunnel at the competition. The requirements for the turbine is explained in Section 2 of this report.

1.3 Original System

The original systems in which we are basing our project off of are the 2016 and 2017 NAU CWC competition teams' wind turbine designs. Design and testing results from the past years design and our design considerations will dictate the use of the older turbines' components or different components in the current design. Due to the CWC rules and requirements changing each year, we will have to build our wind turbine in accordance to the 2018 rules and requirements. Some component requirements are similar each year; therefore, there will be some similarities to the components that have been consistent throughout the competition years. Thus, our overall design will be able to be compared to the past designs for design considerations.

1.3.1 Original System Structure

Looking at NAU's designs from previous years show that there has been a few common component designs. The wind turbine is usually a horizontal axis wind turbine (HAWT) and past years has had the tower blade dimensions set. The blades have been made with some type of 3D printed material (except for a few years ago, when they used carbon fiber). Also, NAU has always gone with a fixed blade, stall regulated turbine with three blades (except for last year with 4 blades). The drivetrain type used in 2017 was a direct drive shaft, and in 2016 there was no shaft (the rotor of the wind turbine connected directly to the generator). The generators used by past teams have had similar dimensions. The DC-DC converter previously used is a simple boost converter, with the board layout being done on a bread board. The PCB board used last year was a simple bread board.

1.3.2 Original System Operation

In past years of this competition, NAU's wind turbines have mostly used fixed blades, a direct drive shaft, an AC-DC generator, and a DC-DC converter. The use of these systems is based off of the ease of operations associated with the systems. Turbine drivetrains on this size scale work well as either a direct drive shaft or no shaft at all (similar to 2017 and 2016, respectively). Direct drive shafts has the turbine rotor fixed on the shaft, which spins the generator at the same rotational speed of the blades. Each year has some different CWC requirements, so our design will mirror the operation of past turbines when allowed and/or needed.

1.3.3 Original System Performance

The performance of the turbine was rated at 22 to 23 Watts at an 11 or 12 meters per second wind speed. The blade performance also showed that a tip speed ratio of roughly 2 to 2.3 at different wind speeds ranging from 10 to 18 meters per second.

1.3.4 Original System Deficiencies

The 2017 NAU CWC competition team had problems mainly with the electronics and braking.

2 REQUIREMENTS

The main customer requirements of this project are based off of the DOE CWC Rules and Requirements [3]. In addition, consultation with our capstone advisor (David Willy) and past CWC competition team members add to the requirements. The customer requirements are then compared with our wind turbine design's engineering requirements, which are measurable and have target values/ranges based on the competition requirements. The customer and engineering requirements' importance are then calculated in a House of Quality model.

2.1 *Customer Requirements*

To design a successful wind turbine, the design must meet the customer requirements set by the CWC website. The main requirements or our design and a description of the reason why each requirement is necessary in Table 1 below. These requirements assure a sufficient customer satisfaction from our overall design.

Table 1. Customer Requirements and Description

Customer Requirement	Description of Reason
Power Generation	There has to be power generated by the wind turbine.
Electrical Grounding	There can be no open charge, so circuits must be grounded.
Transportability	The turbine has to be able to be shipped to and from the competition site and carried by the team.
Assembly	The assembly of the wind turbine should be too complex, so that we can leave room for repairs.
User Friendly	The use of the wind turbine should be as easy as possible for all users, so that there is no confusion at the competition.
Safety	The turbine cannot be harmful to anyone during construction and use.
Durability	The turbine must be able to withstand relevant loading types and values without failure during use.
Maintenance	If failure occurs, the turbine should be easily accessible for maintenance.
Aesthetics	The turbine should look presentable for the competition.
Cost	The turbine cost should not exceed our project budget.

2.2 *Engineering Requirements (ERs)*

For this project, we have come up with several engineering requirements that our team will aim for. Note that all engineering requirements cumulatively satisfy the customer requirements and are relevant to the turbine parts that our team will be building. All of the engineering requirements come from the CWC rules and requirements. Table 2 below displays the engineering requirements along with a description of the reason why each requirement is necessary.

Table 2. Engineering Requirements and Description

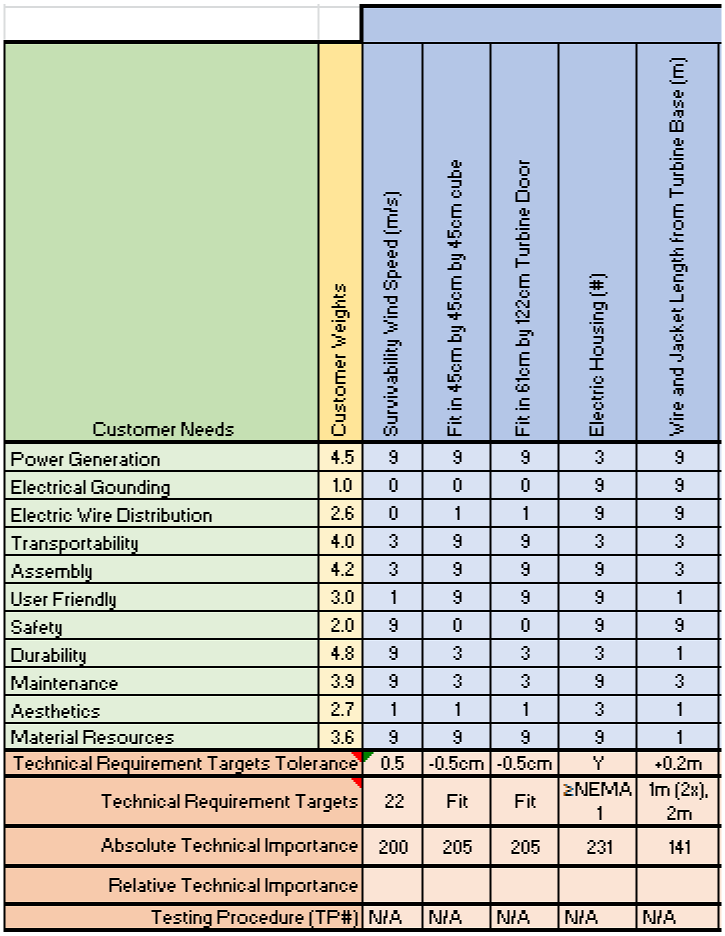
Engineering Requirement	Description of Reason
Survivability Wind Speed (m/s)	The wind turbine must be able to survive winds speeds up to 22 ± 2m/s to survive competition testing.
Fit in 45cm by 45cm by 45cm cube	The wind turbine rotor must be able to fit in a cube for wind tunnel testing with a tolerance of -0.5cm.
Fit in 61cm by 122cm Turbine Door	The wind turbine must be able to be put through the wind tunnel testing turbine door with a tolerance of -0.5cm.
Electric Housing (Y/N)	There must be a housing complex for the electric components of the wind turbine equivalent to or better than the NEMA 1 standard set by the CWC.
Wire and Jacket Length from Turbine Base (m)	The length of the wire and jacket from the turbine base must be at least 1m to and from the load and at least 2m to and from the storage element with a tolerance of +0.2m.
Required Direct Current (DC) at PCC (V)	The DC value at the PCC must be at least 5V and at most 48V.
Zero State of Charge at Test Beginning (C) & (V)	The charge at the beginning of any test must be zero, so as to not expose any charge to people.
Keep Under Energy Storage Rating (V)	The rating of the output into the energy storage unit must be under 16V, or we will fail the test.
Push Shut Down on Command (Y/N)	The wind turbine must have a simple way to shut down the turbine when needed.
Bade Numbers (#)	There must be between 2 to 4 blades on the wind turbine.
Rotor Diameter (cm)	The diameter of the turbine rotor must be below 45cm with a tolerance of about -0.5cm.
Power Curve Generation between 5m/s and 11m/s (W)	The generation of power on the power curve between wind speeds from 5m/s to 11m/s must be maximized (~10 ± 2W).
Cut-in Wind Speed (m/s)	The cut-in wind speed of the wind turbine must be at a wind speed between 2 and 5m/s.
Rated Wind Speed (m/s)	The rated wind speed must be at 11 ± 0.5m/s.
Rated Power (W)	The rated power of the turbine must be at about 10 ± 2W.
Cut-out Wind Speed (m/s)	The cut-out wind speed must be at 20 ± 0.5m/s.
Tip Speed Ratio (#)	The tip speed ratio must be at about 5 to 12.
Overall Efficiency (%)	The overall efficiency of the wind turbine must be about 40 ± 10%.
Aerodynamic Efficiency (%)	The aerodynamic efficiency must be at about 40 to 59%.
Electric Efficiency (%)	The electric efficiency must be at about 90 ± 5%

2.3 *House of Quality (HoQ)*

A House of Quality (HoQ) is created from the CRs and ERs of the previous two sections. The CRs' importance are weighted on a scale from one to five. The ERs relations to the CRs are weighted on a 0-1-3-9 scale (with 9 being the highest relation), and technical requirement targets at the bottom of the HoQ are targets for each ER. Note that there isn't a target value for every ER, as the target of some ERs are arbitrary or different for each component we work with. The absolute technical importance (ATI) is then calculated as:

$$ATI = \sum_{i=1}^{n} [(CR\ Weight)_i * (ER\ Weight)]$$

Based on the ATI, the relative technical importance (RTI) at the bottom of the HoQ displays the most important ERs (one being the most important). Appendix A displays the HoQ. Figure 1 below displays a section of the HoQ for reference of the explanation above.



Customer Needs	Customer Weights	Survivability Wind Speed (m/s)	Fit in 45cm by 45cm cube	Fit in 61cm by 122cm Turbine Door	Electric Housing (#)	Wire and Jacket Length from Turbine Base (m)
Power Generation	4.5	9	9	9	3	9
Electrical Gounding	1.0	0	0	0	9	9
Electric Wire Distribution	2.6	0	1	1	9	9
Transportability	4.0	3	9	9	3	3
Assembly	4.2	3	9	9	9	3
User Friendly	3.0	1	9	9	9	1
Safety	2.0	9	0	0	9	9
Durability	4.8	9	3	3	3	1
Maintenance	3.9	9	3	3	9	3
Aesthetics	2.7	1	1	1	3	1
Material Resources	3.6	9	9	9	9	1
Technical Requirement Targets Tolerance		0.5	-0.5cm	-0.5cm	Y	+0.2m
Technical Requirement Targets		22	Fit	Fit	≥NEMA 1	1m (2x), 2m
Absolute Technical Importance		200	205	205	231	141
Relative Technical Importance						
Testing Procedure (TP#)		N/A	N/A	N/A	N/A	N/A

Figure 1. HoQ Section

3 EXISTING DESIGNS

The existing designs that are researched on pertain to the components that our team will work on. The components are: the blades, shaft, generator, DC-DC converter, and PCB board. These components are sections of an overall wind turbine system that works in unison to produce electrical energy from rotational mechanical energy produced by the fluid wind speed energy. The blades translate the wind speed energy into mechanical energy, while the shaft transfers the mechanical energy into a generator, which translates the mechanical energy into electrical energy. The DC-DC converter then safely steps up the electrical energy to produce the necessary power. The PCB board is the bed that holds all of the electronics while providing a path for electronic transfer.

3.1 Design Research

Since Test Team A works on certain components of the overall turbine, research was done on only the components associated with Test Team A (blades, drivetrain, generator, DC-DC converter, and PCB board).

3.1.1 Research: Blades

When looking at the turbine blades, the airfoils that are being used have a big impact on the blades performance. There are several different companies that have developed airfoils and have released the specifications for how they perform. The National Advisory Committee of Aeronautics (NACA) and the National Renewable Energy Laboratory (NREL) are biggest companies that design airfoils. The NACA 4-digit series is widely used for its simplicity in generating new airfoils. The 4-digits are represented in groups, the last two digits, first digit, and the second digit. The last two digits represent the maximum thickness of the airfoil as a percentage. The first digit represents the maximum camper of the airfoil as a percentage from 0 to 9%. The second digit is an indication of where the maximum camber is in tenths of a percent (0% to 90% in steps of 10%) [4]. The NREL series are a harder to visualize but they break up different airfoils into airfoil families. There are many other airfoils that available for low Reynolds number flow and will be looked at when it is time to select airfoils.

3.1.2 Research: Drivetrain

The research for the shaft consisted of looking through information provided in past NAU Colligate Wind Competition team reports. We have analyzed the test results for the previous drivetrain designs to influence our final decision. We have also used "Shigley's Mechanical Engineering Design" textbook for any drivetrain analysis that maybe applicable. The 2016 didn't have a drivetrain, so they had connect the blade hub to the generator directly. While 2017 team have machined their own design for the drivetrain. Other design that might be considered is a gearbox which also has a pros and cons, which are described in subsequent sections [5].

3.1.3 Research: Generator

One of the power electronics components that our team has to build is the generator. There are several different types of generators that can be used for this project, and all of them have different pros and cons. The main types of generators that were researched for this project were a permanent magnet AC generator, a DC generator, or a rewired AC generator that we would optimize for this project. The first design, permanent magnet AC, is the simplest of the 3. It works by turning magnets around fixed coils of magnet wire. The alternating north and south poles of the magnets induce an alternating current in the wire, which can then be sent to our rectifier. For the permanent magnet generator, the advantages are that we can get a good power output and keep the generator size small. This is also the kind of generator that has been used by almost every other CWC team so it is well established and reliable. The drawbacks are that we get a low voltage output because of the fairly high KV rating (RPM/V) from this type of generator. A DC generator also works by inducing current in coils of magnet wire, but the way it does it is different. In a DC generator, the coils rotate in a fixed field. The coils are attached to a commutator, which balances the charges coming into and going out of the generator, resulting in a direct current output. The advantages of a DC generator are that it eliminates the need for a rectifier and can be built fairly easily. The disadvantages are that it is larger, requires more maintenance, and is less efficient than its AC counterpart. A rewired AC generator is something we would create for this project, where we would take an AC generator apart and then try to put it back together with thinner gauge wire, which would allow us to decrease our KV rating, therefore increasing our voltage output. The advantages of a rewired AC generator are the same as the normal AC generator, with the added bonus that we can get more voltage out of it since we are rewiring it to optimize it for this project. The disadvantage of doing this is that it will take a lot of careful work and if a mistake is made in the rewiring process it could ruin the generator and we would have to get a new one [6].

3.1.4 *Research: DC-DC Converter*

An important part of the turbine design is the power electronics. Our team has been assigned the task of designing the DC-DC converter. The purpose of the DC-DC converter will be to boost the output voltage of the system. There are various types of boost converters, all with specific advantages and disadvantages. As part of the research, we have looked at previous DC-DC converters used by past CWC teams. The 2017 Northern Arizona University team utilized a standard boost converter topology in their converter. Along with analyzing previous devices, we have begun researching several different types of converters. Performing simulations will help to design and optimize the DC-DC converter to best fit the wind turbine. The simulations will be conducted in the Simulink software package and this will require knowledge of the program. This has required us to watch tutorials on designing schematics in Simulink.

3.1.5 Research: PCB Board

I found a book which is describe how to choose different types of PCB board, and what are the advantages and drawbacks in these four designs. According to customer requirements and engineering requirements, our client requires the durability of board has to be good, and the board should be minimized the cost. Therefore, I am focusing on the pros and cons in all designs and determining which design can meet the requirement and improving a good efficiency [7].

3.2 System Level

The component work in which we are undertaking contributes to an overall small-scale wind turbine that will be tested within a wind tunnel. In other words, the overall system of a wind turbine can be constructed in multiple ways based on the subsystem components. The existing subsystems' that we are assigned to work on are in the subsequent 3.2 sections.

A bigger-scale but similar type of wind turbine that exhibits the relativity and applicability of our project is the GE 1.5MW Wind Turbine. The GE 1.5MW Wind Turbine is a HAWT that includes the subsystems similar to our assigned subsystems: the blades, main shaft/gearbox, generator, converter, and board for electronics. This wind turbine is being implemented into various grid networks to continue to increase the wind energy production of the planet [8].

A smaller-scale home wind turbine that exhibits the relativity and applicability of our project is the 400-Watt Wind Turbine Power Generator for 12-Volt Systems from Home Depot. It's a HAWT wind turbine with three blades that customers can use "in their own back yard" for necessary energy applications. It has all of the similar components as the turbine in which we are building. It can charge batteries, be used with an inverter to produce power for applicable electronics (like a T.V., lights, and/or power tools) [9].

Another small scale wind turbine that exhibits the relativity and applicability of our project is the Primus Wind Power Air 40 12 Volt DC Turbine from Norther Arizona Wind & Sun. It is a three blade HAWT that works in "medium to high wind environments [10]." It too has similar components to the turbine in which we are building.

3.2.1 Subsystem Level: Blades

The blades of wind turbine are used to convert linear momentum of the wind into rotational energy of the shaft. The purpose of the blades is to generate lift causing the blades to rotate around the shaft axis. The blades are made up of different airfoils that are designed to work at different sections of the blade. The air foils need to be matched with the Reynolds number that the blade is operating at. This is important because each airfoil is designed to operate at a certain section of the airfoil and at certain Reynolds number ranges. The blades are a vital component because without them the turbine would be a giant pole in the ground.

3.2.1.1 Existing Design: Blade Material

Many of the current wind turbines for the DOE CWC have been made of carbon fiber and some type of 3-D printed material. The difference between carbon fiber and 3-D printed materials is the strength of material. Carbon fiber has mainly been used when deflection of the turbine's blades needed to be minimized and fewer number of blades were needed. 3-D printed material on the other hand were used when costs need to be low or a large number of blades were needed to be made. The application of material selection is important for the performance of the turbine. The material also greatly affects what type of airfoils that we can use. With the carbon fiber thinner airfoils are possible because molds are being used to form the blades. While thinker airfoils need to be used if the material is 3-D printed. During the 3-D printing process the tip resolution can only be so good, meaning the blade's design has to be something that the printer can handle meaning thinker airfoils.

3.2.1.2 Existing Design: Blade Types

When looking at the blade of a wind turbine the airfoils at the root (base) and tip of the blade are going to be different. In past years the teams have used the NACA 4-digite series airfoils. The reason that this series has been used is because it is easy to visually see what the airfoil is going to look like. The airfoils that are being used for the blades of the generally represent high lift airfoils. These airfoils are used for the lift that they create. The use of flat plates are not used for the turbine blades, however they are used for the tail fin.

3.2.2 Subsystem Level: Drive Train

There are different kinds of drive trains: two we will be looking at are a gearbox and a direct drive shaft. The material of the shaft dictates its overall life based on geometrical constraints and the loading factors. The necessary power requirements dictate what type of shaft will be used for rotational momentum transfer from the rotor and hub to the generator. The material of the disk brake dictates the weight of the gear and how well the brake will work (based on the friction).

3.2.2.1 Existing Design: Gear Box or Direct Drive

The shaft of the wind turbine is connected in a fixed position to the hub, spins and stabilizes on clearance-fit bearings, holds a gear that acts as a disc brake, and connects to the generator to translate rotational momentum into electrical energy. The material of the shaft dictates its overall life based on geometrical constraints and the loading factors. The necessary power requirements dictate what type of shaft will be used for rotational momentum transfer from the rotor and hub to the generator.

3.2.2.2 Existing Design: Drive Train Material

The shaft is used to convert mechanical energy to electrical energy. It connects the hub and blades to the generator. So, we need to consider how these different components connected to the shaft. For example, we will use shaft to connect blades and generator, so we need to connect a shaft which can withstand the loading variables. Gearbox is a set of shafts and gears. Gearbox can be used in wind turbine to increase the low rpm that coming from the blades. As a result, the higher rpm number will be translated to the generator so the voltage produced will increase. On the other hand, the direct drive shaft is a shaft that connect the blades to the generator to translate the kinetic rotational energy from the blades to the generator to be converted to electrical energy [12].

3.2.2.3 Existing Design: Disk Brake Material

The turbine needs to be able to sustain the wind speed up to 20m/s. Therefore, it is important to consider the material of the shaft. We need to consider the hub, bearings, brake disk, and generator connected to the shaft. As these factors considered, we need to pick a material that can handle a high amount of torque that will be applied by the blades, the brake and the generator. Also, the material needs to be hard enough to endure the forces and loads that will be applied by the bearings and the hub.

3.2.3 Subsystem Level: Generator

The generator is what converts the mechanical energy of the blades into usable electrical energy. It does this by rotating magnets around several tightly wound coils of magnet wire. This induces a current in the wire, which can be either AC or DC based on the type of generator and the components inside of it. This voltage is then fed into our rectifier (if AC) or directly into or DC-DC converter (if DC).

3.2.3.1 Existing Design: Danish Wind Industry Association

This type of generator is the one all of the previous CWC teams have used. It is a fairly simple design, is reliable, and has a decent KV rating. The problems with this type of design are that it has a fairly low voltage output so it is hard to get a competitive voltage value during the competition.

3.2.3.2 Existing Design: Permanent Magnet Generator Design

This type of generator is much like the AC generator, but instead of the magnets rotating around the coils, the coils instead rotate inside a fixed field. The coils are then attached to a commutator, which gives a DC output. The advantages of this are that it directly produces DC current so we don’t have to convert it with a rectifier. The downside is that DC generators are less efficient, larger, and require more maintenance.

3.2.3.3 Existing Design: Rewired AC Generator

This design is just a modified version of the fixed magnet AC generator. We would take an AC generator and take the current coils out so we could put new ones in with a thinner gauge wire. This would increase the number of turns which would increase our voltage. It would also take a lot of time and effort on our part though and there is no guarantee that it would significantly increase our voltage.

3.2.4 Subsystem Level: DC-DC Converter

The main purpose of the DC-DC converter is to step the input voltage up to around 48 volts. In order, to do this the system utilizes inductors, capacitors, transistors and other electrical components to achieve a higher output voltage.

3.2.4.1 Existing Design: Boost Converter

A boost converter is a simple DC-DC converter that steps up the voltage through an inductor, capacitor, MOSFET and a diode. The device would function as a switch mode supply to step the voltage up.

3.2.4.2 Existing Design: Interleaved Boost Converter

This circuit is a more complicated form, of a boost converter. It is often called a multichannel converter as it contains to channels of inductors and MOSFET's operating 180 degrees out of phase. It has a high efficiency and requires more components than a boost converter.

3.2.4.3 Existing Design: Buck-Boost Converter

This design is another variant of a boost converter, it contains additional diodes and is a bit more complicated. The overall operating principal is the same with an added feature. When the pulse width of the MOSFET transistor is below 50% it operates as a buck converter. This device would provide the ability to either step the voltage up or down based off the pulse width.

3.2.5 Subsystem Level: PCB Board

PCB board means Printed Circuit Board. It is a carrier which can connect between software and hardware. It is a high precision and high reliable device. It is also an important part in the wind turbine, because when we design a circuit and tested successfully, we need to make our circuit into a board so that we can connect generator to the DC-DC converter.

3.2.5.1 Existing Design: Single-Side Board

Single-side board is an original design in the PCB board. But there always have some factories using the single side board to design some circuit in the TV and DVD players. It can reduce the cost of the board. It means if you can design a circuit using a single side board, that will be good. But there are many constraints on components placement when using this design.

3.2.5.2 Existing Design: Double-Side Board

Double-side board gives us an extra layer that we can put our components more easily. The area of the board will be smaller than single-side board because there are more tiny chip capacitors and resistors are using in the circuit. These chip capacitors only use in the bottom layer to improve the circuit efficiency and reduce the error.

3.2.5.3 Existing Design: Multi-layer Board

There are four layers in the multi-layer board design, we have top layer; bottom layer; VCC layer, and GND layer. This design focuses on some complex circuit design, because we need to use single layer to put the VCC and GND, it will improve the efficiency, but there are more work to do and the cost is more expensive than other two types.

3.2.5.4 Existing Design: Bread Board

The bread board is a board which we can directly use to connect our circuit. Because the board has many holes that we can directly use, but this design will increase the line resistance and decrease the output voltage. This design can connect the control theory more easily because the circuit and the control part can be connected together [7].

3.3 Functional Decomposition

The functional decomposition for this project can be found in Appendix B. Within the functional decomposition the different components of the turbine have been broken down into analytical terms. It also contains possible design choices that come along with each component. As shown in the functional decomposition, the main sections of the wind turbine include the power electronics (DC-DC converter and rectifier), the load (capacitor bank and batteries), the generator (AC/DC Generator), and the mechanical structure (blades, hub, shaft, yawing, nacelle, and tower). The components that Test Team A work on include: the blades, the shaft, the generator and the DC-DC converter.

3.3.1 Black Box Model

The wind turbine black box model shown in Figure 1 displays the necessary material, energy, and signal inputs with their corresponding outputs to translate mechanical energy into electrical energy on a wind turbine. The inputs necessary include the wind speed and direction which rotates the rotors (translating wind energy into mechanical energy) and a start, break, and stop feature for applications of these signals before and/or during operation. Then, mechanical energy is translated into electrical energy through a shaft and generator design that produces electricity and a DC-DC converter that steps up the electrical energy. The signaling output for a working turbine shows the rotor spinning and allows for working electronics when the wind turbine is on, while the rotor would be stationary and the electronics wouldn’t work when it’s off. The black box model helps our team understand the major material, energy, and signals associated with completing our overall goal. The necessary inputs are the building blocks of our components’ functionality, while the outputs are the goals each component must work toward for proper wind turbine functionality.

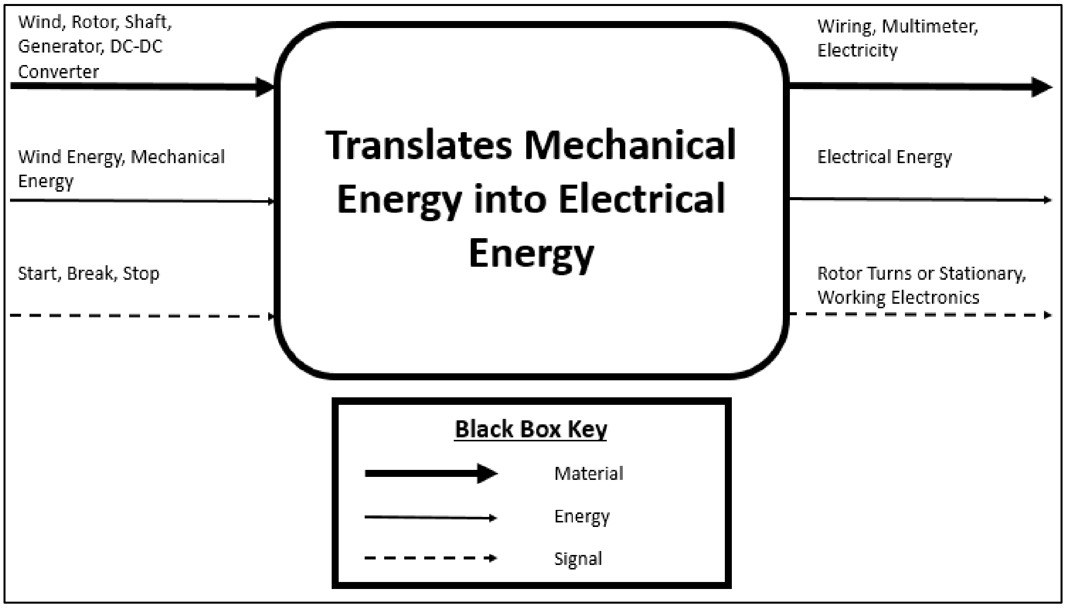


Figure 2. Wind Turbine Black Box Model

3.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

Appendix C shows the Gantt Chart of the entire collegiate wind competition team. Within the headings are each teams' deliverables and a timeline for completion. Test Team A's deliverables are displayed in Appendix C. This Gantt chart helps us clarify our timeline to complete necessary deliverables in a timely manner.

4 DESIGNS CONSIDERED

The following sections pertain to the considered component designs for the blades, drivetrain, generator, DC-DC converter, and PCB board.

4.1 Design: Blades

By generating different ideas than those that have been used by existing ideas. The benefits of coming up with new ideas for the blades it is possible come up with a design that can generate more power or be more efficient.

Through the concept generation process many designs were created to increase either the performance, power, or efficiency of the blades. The first concept (shown in figure 3) that was created was to trying to increase the Reynolds number (Re) that the blades are acting at. By increaaseing the Re there is a larger selection of airfoils that would be able to use. Therefore, potentially increaseing the power generated for the turbine's.

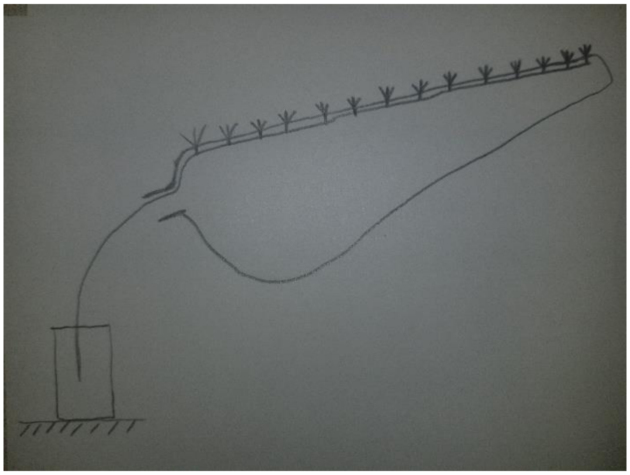


Figure 3. Design 1 – fluid nozzles to increase Reynolds number

The Second design created (shown in figure 4) was a teliscoping blade. The purpose of design was to be within the size restriction of the competition, but once the blade starts rotation and the centripital force increase the length of the blade increase the torque of the turbine, increaseing the amount of power that can be produced. Since there are a lot of forces on the turbine blades this design would need a lot of analisys to determin if the blades would survive under all the stress at higher wind speeds.

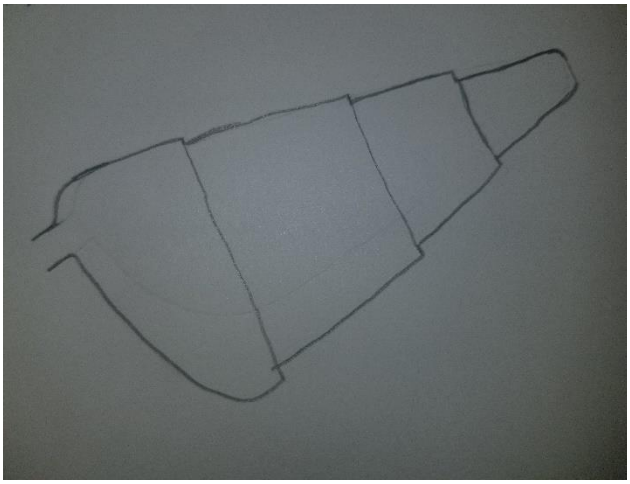


Figure 4. Telescoping blade design

The next design (shown in figure 5) is a blade that is curved. The reason for the curve on the blade is to decrease the noice that is produced at higher revolutions per minute of the turbine blades. While reducing noice it increases the tip losses. With the increased tip losses the performance of the turbine would decrease and be less efficient. However, because of the shape of blades it would have an appleling factor that customers might like.

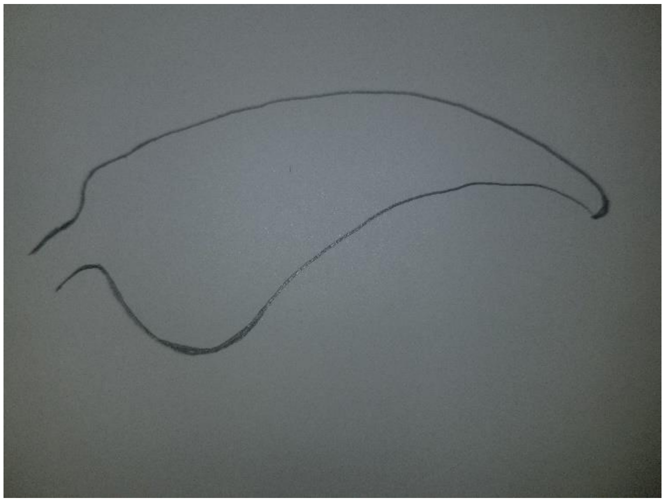


Figure 5. Curved blade design

Another design that was taken from an automotive application is the use of a shroud (shown in figure 6). The use of the shroud would cut down on wake rotation. By cutting down on wake rotation it the blades would behave more like a betz blade. The shroud would also act as a small nozzle increase the velocity of the flow as it enters the upstream side of the blades. Since the power in the wind is equal to the cuvbe of the velocity, the amount of power that the turbine can generate would be increased.

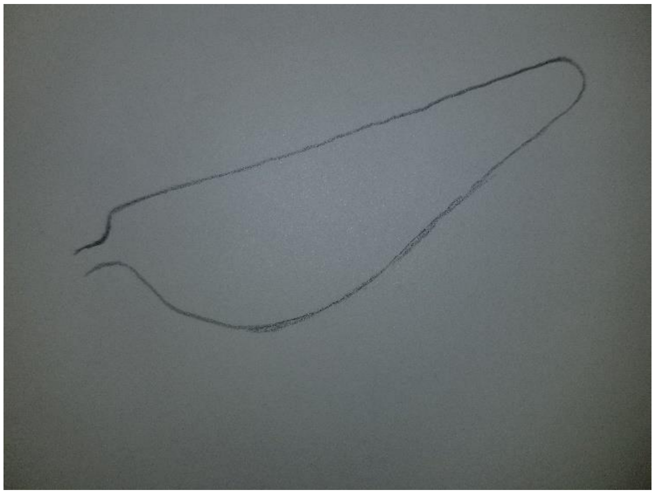


Figure 6. Conventional blade design

A typical blade for a wind turbine (shown in figure 7) is simple and does not require extra calculations to determin the amount of power that the turbine is producing. A normal design like this is the most commonly used.

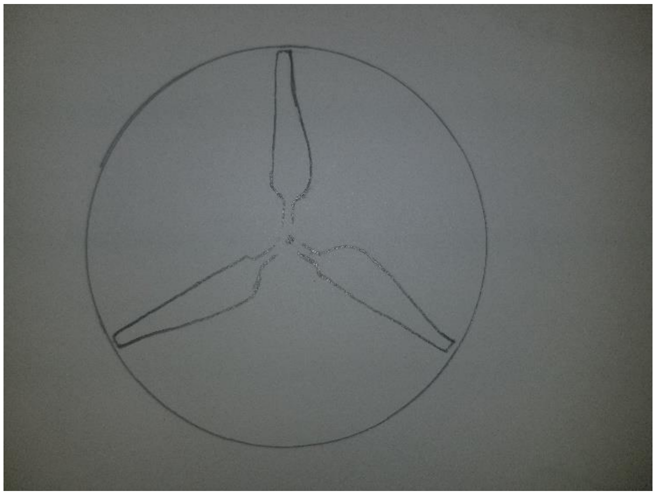


Figure 7. Shroud around turbine blades

4.2 Design: Drivetrain

There are two designs we have considered, the first design that we have considered is the gearbox drive. The pros of the gearbox are: increased rpm and increased power output; the cons include: higher probability of failure, complication in design, and overall cost. The second design we are considering is a direct drive shaft. The pros of the direct drive shaft are: cheaper, reliability, easier to design. While the cons of the direct drive shaft are: less rpms, less voltage production. The material of the disk brake will be decided on a later date, as there needs to be consulting with the brake team.

4.3 Design: Generator

The 2 main generator designs that we are considering right now are a rewired AC generator or a permanent magnet AC generator. We chose these two because they best meet the needs for this project. Our generator needs to be small and efficient, and a DC generator is neither of those things. When deciding between rewired or permanent magnet, the main factor will be which one is more important to the team, having a great generator or having more time available to help with other components we are building.

4.4 Design: DC-DC Converter

In order, to decide which type of DC-DC converter to utilize for our system, we conducted research to find which converter would best match the needs of our project. Ultimately, we came up with four different designs to consider: boost converter, interleaved boost converter, flyback converter and a buck-boost converter. Upon further research, we eliminated the flyback converter because of its difficulty to implement, and that it required a transformer. Also, with the equipment available to our team we would not be able to successfully build and test the converter. The buck-boost converter could be eliminated based on premise that our system would only need to step the voltage up and it would not be necessary to step down the voltage. This left two designs remaining, from there we built two Simulink models for each converter.

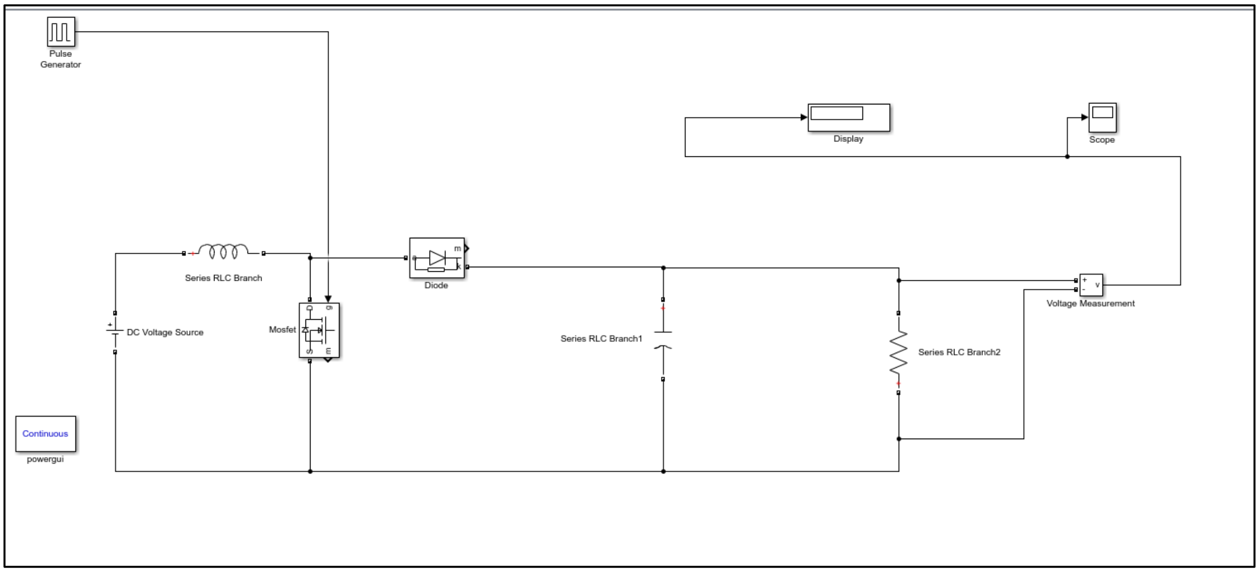


Figure 8: Boost converter

The figure above is a schematic of a boost converter that was designed for the project. It is a simple design, which will make designing the converter relatively simple. However, it does not offer several of the advantages of an interleaved boost converter.

A interleaved boost converter or multi-channel boost converter, as seen in the schematic below would require more components than a typical boost converter; however, we believe the advantages are well worth the extra effort to implement. By having a multi-channel converter, the overall efficiency of the system would be improved along with reduced voltage ripple and shrinking the inductor and capacitor size [13].

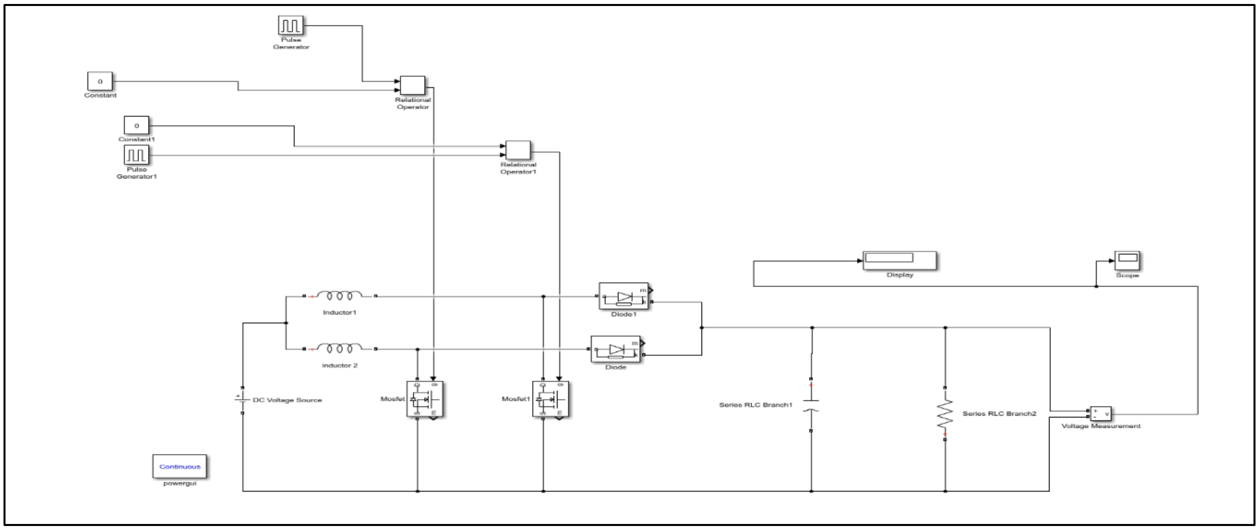


Figure 9: Interleaved boost converter

4.5 Design: PCB Board

There are different types of wiring diagram that we can use in our project. All of them has advantages and disadvantages. The simplest way is single-side board, the advantages of this design is easy to correct error, but the lines we use to connect components cannot cross. Secondly, the double-side board, the advantages are that the size is better than single-side board, and some components which can only use in bottom layer. the drawback of this design is that it will increase the area of the wiring, because sometimes we need to use wire to connect the top layer and bottom layer. The complex design is multi-layer board, it will be applied to sophisticated circuit design. For our converter design, I believe the double-side board will be the best one. because there are some chip capacitors need to put in the bottom layer, and the circuit is not much complex, therefore, we do not need to use multi-layer board.

5 DESIGN SELECTED

The rationale for the designs considered is implemented in this section. Each individual worked on their assigned section; thus harboring different criteria for decision matrices (if the person decided to add one to their work).

5.1 *Rationale for Design Selection*

5.1.1 Selection: Blades

After the concept generation stage of the design process, and initial design is needed to be selected. With design 2 and the blade length increasing, it pushes the blades outside the allowed area for the turbine. Therefor that design has to be scrapped. With design 3, the amount of power that the turbine is going to produce, extra losses from the tip of the blades would be bad decision and would almost be impossible to recover from the losses this design. Therefore, this design was also scrapped in order to maximize the amount of power that the turbine can generate. After scrapping designs 2 and 3, a closer look at how the manufacturing of the blades would occur was needed. The diameter of fluid pipe would be extremely small in order to fit within the thickness of the turbine blades. For this reason design this was also scrapped. After looking at the concepts that remain, design 5 selected as the initial design for the simplicity and reliability of the blades at higher wind speeds.

5.1.2 Selection: Drivetrain

The drivetrain is going to be designed as a short direct drive shaft that directly connects the blades hub to the generator while providing a disk brake gear with different material. The direct drive shaft is less complicated will have less factors for failure, while providing adequate rotational momentum transfer. Table 3 below displays the decision matrix used to come to our drivetrain decision. The direct drive shaft outscored the gearbox in all categories besides the functionality aspect, as the gearbox increases the revolutions per minute entering into the generator.

Table 3. Drivetrain Decision Matrix

	Weights	Direct drive shaft	Gearbox
Reliability	0.60	8	4
Size	0.05	8	6
Functionality	0.20	5	8
Ease of implementation	0.15	7	4
Total	1.00	7.25	4.9

5.1.3 Selection: Generator

For this project, we have decided to use a rewired AC generator because it will give us the best voltage output compared to the other options. Even though it takes more time and effort and there are risks involved with it, we want to have the best possible generator for the competition and we believe this is the best way to get such a generator. When we put the options into our decision matrix, it gave the same result, which is that a rewired AC generator was the best option.

Table 4. Generator Decision Matrix

Criteria:	Cost	Performance	Time/Effort	Size	Complexity	Total Score
Criteria Weights(1-5):	2	5	3	3	3	

Permanent Magnet AC	8	6	9	8	7	118
DC	6	4	9	6	4	89
Rewired AC	7	10	6	8	6	124

5.1.4 Selection: DC-DC Converter

Our initial selection, we used a pairwise matrix and a decision matrix to help select which converter to go with. The weighting from the decision matrix is based off the values determined by the pairwise matrix. From the outcome of the decision matrix, we believe an interleaved boost converter, will best fit the scope of the project. An interleaved boost converter offers several advantages: improves efficiency, reduces ripple, and shrink capacitor and inductor sizes [1]. The criteria for the DC-DC converter matrices are:

1. Reliability: The final product will need to work a high percentage of the time.
2. Ease of Implementation: Developing the DC-DC converter will require a lot of work to design. Being able to limit this work could potentially save time.
3. Functionality: The functionality is very broad, and encompasses other important characteristics like voltage ripple and device efficiency.
4. Size: The team has a limited space that the device needs to fit into.

Furthermore, in table 5, the scale that we are using goes from one to nine. Nine being the best that a criterion can achieve and one the lowest.

Table 5. DC-DC Converter Decision Matrix

	Weights	Boost Converter	Interleaved Boost Converter
Reliability	.55	6	5
Size	.06	6	5
Functionality	.31	5	8
Ease of Implementation	.08	7	6
Total	**1**	**5.77**	**6.01**

Table 6 represents the pairwise matrix that will be used to determine the weighting of the criteria. The weighting will be used to determine the best DC-DC converter in the decision matrix.

Table 6. Pairwise Matrix for DC-DC Converter

	Reliability	Size	Functionality	Ease of Implementation	**Weight**
Reliability	1	7	3	5	**.55**
Size	1/7	1	1/4	1/2	**.06**
Functionality	1/3	4	1	8	**.31**
Ease of Implementation	1/5	2	1/8	1	**.08**

5.1.5 Selection: PCB Board

According to the requirement of customer and enginering: the electrical board area should be minimized to decrease cost and allow for needed electric systems, it should be easily replaceable and it also has to a good durability.We can build a Decision Mtrix to determine which design is better to use in our project.

	Cost	Replaceable	Durability	Total
Single-Side board	Low-cost:2*1=2	High-replaceable 1*3=3	Medium-durability:2*5=10	15
Double-side board	High-cost:2*3=6	Low-replaceable: 1*1=1	High-durability: 3*5=15	22
Multi-layer board	Medium-cost:2*2=4	Medium-replacement:2*1=2	Low-durability: 1*5=5	11

Criterias: Cost----5. Repalceable-----1. Durability----2

Influence: High----3; Medium----2; Low----1

From the decision matrix, we can easily see the double-side board is the best choice in our project.

6 REFERENCES

[1] “Collegiate Wind Competition | Department of Energy”, *Energy.gov*, 2017. https://energy.gov/eere/collegiatewindcompetition/collegiate-wind-competition

[2] B. Merchant “US Wind Power Is Expected to Double in the Next Five Years”, *Motherboard*, 2017. https://motherboard.vice.com/en_us/article/vvbq33/american-wind-power-is-expected-to-double-by-2020

[3] “Collegiate Wind Competition 2018”, U.S. Department of Energy, 2017.

[4] M. Jureczko, M. Pawlak and A. Mezyk, “Optimisation of wind turbine blades”, *ScienceDirect*, 2017 http://www.sciencedirect.com/science/article/pii/S0924013605005856#aep-section-id28

[5] Budynas.R and Nisbett. J, ’*Shigleys mechanical engineering design’*. New York, NY: McGraw-Hill Education, 2015

[6] H. Trencher, “Differences Between AC & DC Generators,” It Still Works. [Online]. Available: https://itstillworks.com/differences-between-ac-dc-generators-7636332.html. [Accessed: 02-Oct-2017].

[7] D. L. Jones, “PCB Design Tutorial” June 29th 2004, pp.3-25

[8] GE Energy, “1.5MW Wind Turbine”, 2017.

[9] “Nature Power 400-Watt Wind Turbine Power Generator for 12-Volt Systems-70500”, *The Home Depot*, 2017. http://www.homedepot.com/p/Nature-Power-400-Watt-Wind-Turbine-Power-Generator-for-12-Volt-Systems-70500/203916953

[10] Norther Arizona Wind & Sun, “Primus Wind Power Ait 40 12 Volt DC Turbine”, 2017. https://www.solar-electric.com/primus-wind-power-air-40-12-volt-generator.html?gclid=EAIaIQobChMIoIm9_cnd1gIVCbbACh1jSAI5EAkYBCABEgK8n_D_BwE

[11] *How do Wind Turbines work?*. YouTube: Learn Engineering, 2017. https://www.youtube.com/watch?v=qSWm_nprfqE

[12] J. Manwell, J McGowan and A. Rogers, *Wind Energy Explained*, 2nd ed. Chichester, West Sussex: John Wiley & Sons Ltd., 2017.

[13] J. S. A. Rahavi, T. Kanagapriya and R. Seyezhai, "Design and analysis of Interleaved Boost Converter for renewable energy source," *2012 International Conference on Computing, Electronics and Electrical Technologies (ICCEET)*, Kumaracoil, 2012, pp. 447-451.

[14] “Wind Turbine Blade Design, Flate Blades or Curved Blades”, *Alternative Energy Tutorials*, 2017. http://www.alternative-energy-tutorials.com/energy-articles/wind-turbine-blade-design.html.

[14] “Wind Turbine Generators”, Xn—drmstree-64ad.dk, 2017. http://xn--drmstrre-64ad.dk/wp-content/wind/miller/windpower%20web/en/tour/wtrb/electric.htm

[15] A. Grauers, “Design of Direct-driven Permanent-magnet Generators for Wind Turbines”, *Chalmers Publication Library(CPL)*, 2017. http://publications.lib.chalmers.se/publication/1044

[16] “Design and analysis of Interleaved Boost Converter for renewable energy source – IEEE Conference Publication”, *ieeexplore.ieee.org*, 2017. http://ieeexplore.ieee.org/abstract/document/6203850/

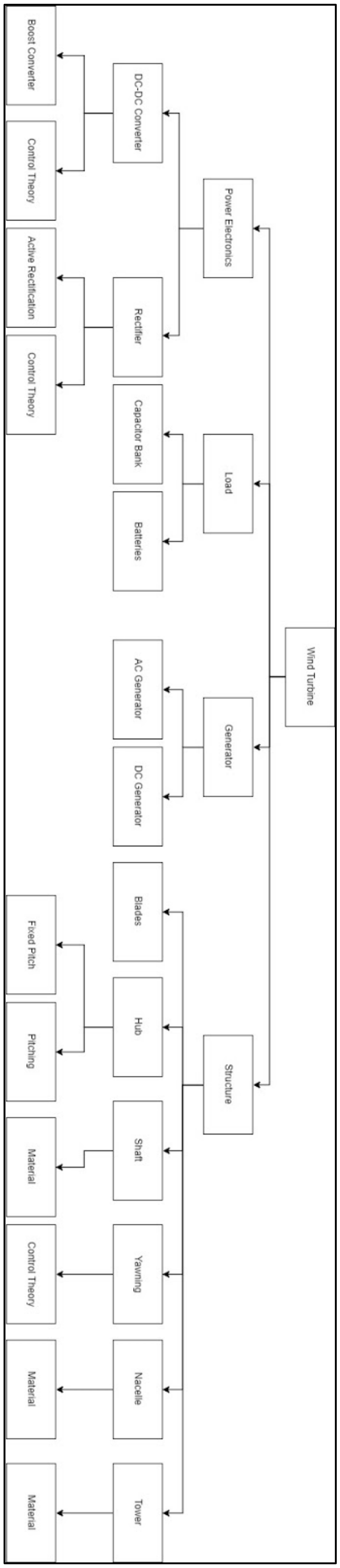
[17] C. N. M. Ho, H. Breuninger, S. Pettersson, G. Escobar, L. A. Serpa and A. Coccia, "Practical Design and Implementation Procedure of an Interleaved Boost Converter Using SiC Diodes for PV Applications," in *IEEE Transactions on Power Electronics*, vol. 27, no. 6, pp. 2835-2845, June 2012.

7 APPENDICES

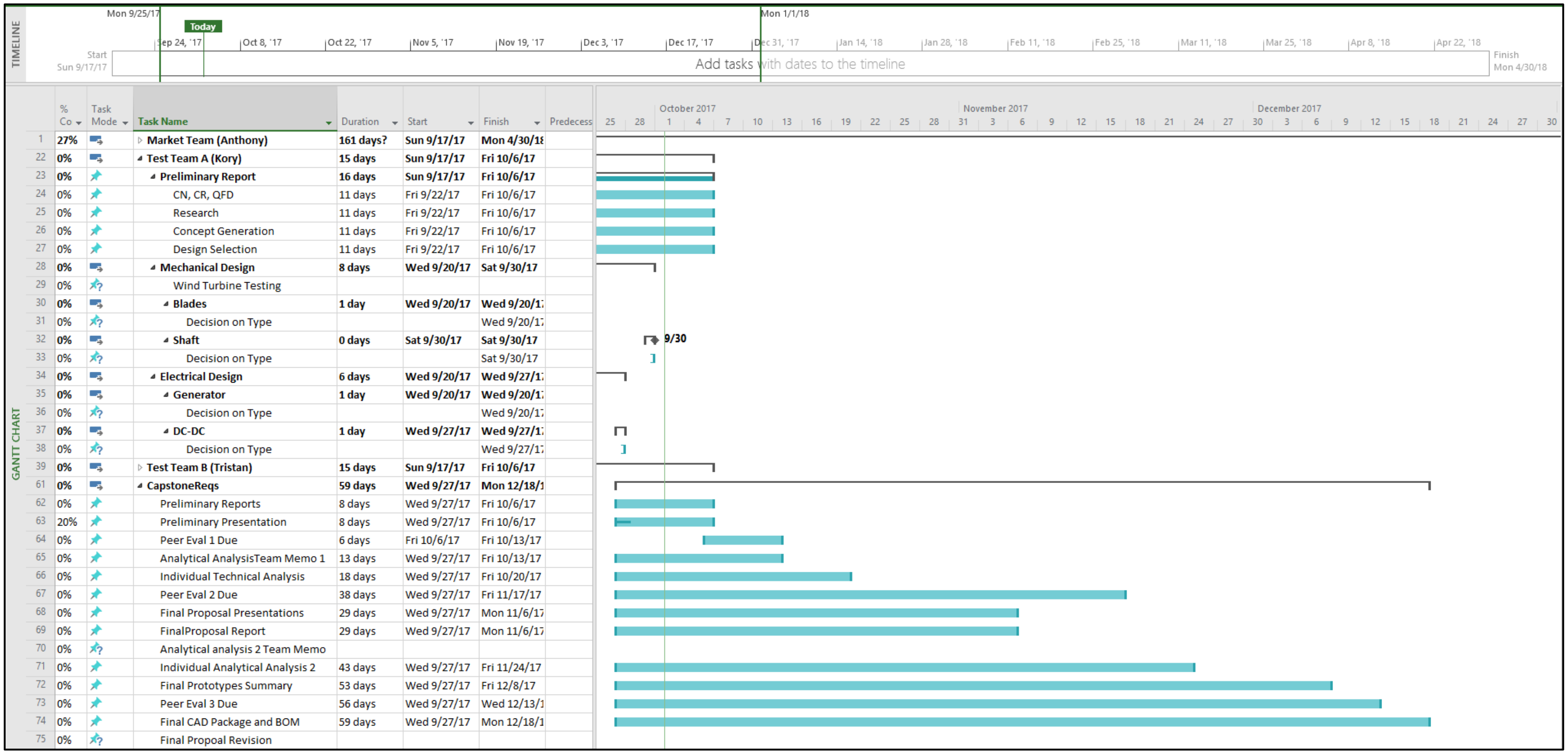
7.1 *Appendix A: House of Quality (HoQ)*

		Technical Requirements																			
Customer Needs	Customer Weights	Survivability Wind Speed (m/s)	Fit in 45cm by 45cm by 45cm cube	Fit in 61cm by 122cm Turbine Door	Electric Housing (#)	Wire and Jacket Length from Turbine Base (m)	Required Direct Current (DC) at PCC (V)	Zero State of Charge at Test Beginning (C) & (V)	Keep Under Energy Storage Rating (V)	Push Shut Down on Command (Y/N)	Blade Numbers (#)	Rotor Diameter (cm)	Power Curve Generation between 5m/s and 11m/	Cut-in Wind Speed (m/s)	Rated Wind Speed (m/s)	Rated Power (W)	Cut-out Wind Speed (m/s)	Tip Speed Ratio (#)	Overall Efficiency (%)	Aerodynamic Efficiency (%)	Electric Efficiency (%)
Power Generation	4.5	9	9	9	3	9	9	1	9	1	9	9	9	9	9	9	9	9	9	9	9
Electrical Gounding	1.0	0	0	0	9	9	9	9	3	3	0	0	3	1	1	1	1	0	3	0	9
Electric Wire Distribution	2.6	0	1	1	9	9	3	9	1	1	0	0	3	3	3	3	3	0	3	0	9
Transportability	4.0	3	9	9	3	3	1	0	0	3	3	9	3	3	3	3	3	3	9	9	3
Assembly	4.2	3	9	9	9	3	3	0	1	9	9	9	9	9	9	9	9	9	9	9	9
User Friendly	3.0	1	9	9	9	1	1	9	9	9	3	3	9	9	9	9	9	3	9	9	3
Safety	2.0	9	0	0	9	9	3	9	9	9	1	9	9	9	9	9	9	3	1	1	3
Durability	4.8	9	3	3	3	1	3	1	3	3	9	9	9	9	9	9	9	9	1	1	3
Maintenance	3.9	9	3	3	9	3	1	3	9	3	9	9	9	9	9	9	9	9	9	9	3
Aesthetics	2.7	1	1	1	3	1	1	0	1	1	3	3	3	3	3	3	3	3	1	1	3
Material Resources	3.6	9	9	9	9	1	3	3	3	3	9	9	9	9	9	9	9	3	9	9	9
Technical Requirement Targets Tolerance		0.5	-0.5cm	-0.5cm	Y	+0.2m	V	C	-3V	Y	#	-0.5cm	+2W	-2m/s	0.5m/s	1kW	4m/s	#	10%	-19%	5%
Technical Requirement Targets		22	Fit	Fit	≥NEMA 1	1m (2x), 2m	5 to 48V	0	16V	Y/N	2 to 4	45cm	10W	5m/s	11m/s	2kW	25m/s	5 to 12	40%	59%	90%
Absolute Technical Importance		200	205	205	231	141	115	109	158	145	220	260	265	263	263	263	263	203	229	218	204
Relative Technical Importance																					
Testing Procedure (TP#)		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		N/A

7.2 *Appendix B: Functional Decomposition*



7.3 *Appendix C: Gantt Chart*



	% Co	Task Mode	Task Name	Duration	Start	Finish	Predecess
1	**27%**	➔	▷ **Market Team (Anthony)**	**161 days?**	**Sun 9/17/17**	**Mon 4/30/1**	
22	**0%**	➔	◢ **Test Team A (Kory)**	**15 days**	**Sun 9/17/17**	**Fri 10/6/17**	
23	**0%**	📌	◢ **Preliminary Report**	**16 days**	**Sun 9/17/17**	**Fri 10/6/17**	
24	0%	📌	CN, CR, QFD	11 days	Fri 9/22/17	Fri 10/6/17	
25	0%	📌	Research	11 days	Fri 9/22/17	Fri 10/6/17	
26	0%	📌	Concept Generation	11 days	Fri 9/22/17	Fri 10/6/17	
27	0%	📌	Design Selection	11 days	Fri 9/22/17	Fri 10/6/17	
28	**0%**	➔	◢ **Mechanical Design**	**8 days**	**Wed 9/20/17**	**Sat 9/30/17**	
29	0%	📌?	Wind Turbine Testing				
30	**0%**	➔	◢ **Blades**	**1 day**	**Wed 9/20/17**	**Wed 9/20/1**	
31	0%	📌?	Decision on Type			Wed 9/20/1	
32	**0%**	➔	◢ **Shaft**	**0 days**	**Sat 9/30/17**	**Sat 9/30/17**	
33	0%	📌?	Decision on Type			Sat 9/30/17	
34	**0%**	➔	◢ **Electrical Design**	**6 days**	**Wed 9/20/17**	**Wed 9/27/1**	
35	**0%**	➔	◢ **Generator**	**1 day**	**Wed 9/20/17**	**Wed 9/20/1**	
36	0%	📌?	Decision on Type			Wed 9/20/1	
37	**0%**	➔	◢ **DC-DC**	**1 day**	**Wed 9/27/17**	**Wed 9/27/1**	
38	0%	📌?	Decision on Type			Wed 9/27/1	
39	**0%**	➔	▷ **Test Team B (Tristan)**	**15 days**	**Sun 9/17/17**	**Fri 10/6/17**	
61	**0%**	➔	◢ **CapstoneReqs**	**59 days**	**Wed 9/27/17**	**Mon 12/18/1**	
62	0%	📌	Preliminary Reports	8 days	Wed 9/27/17	Fri 10/6/17	
63	20%	📌	Preliminary Presentation	8 days	Wed 9/27/17	Fri 10/6/17	
64	0%	📌	Peer Eval 1 Due	6 days	Fri 10/6/17	Fri 10/13/17	
65	0%	📌	Analytical AnalysisTeam Memo 1	13 days	Wed 9/27/17	Fri 10/13/17	
66	0%	📌	Individual Technical Analysis	18 days	Wed 9/27/17	Fri 10/20/17	
67	0%	📌	Peer Eval 2 Due	38 days	Wed 9/27/17	Fri 11/17/17	
68	0%	📌	Final Proposal Presentations	29 days	Wed 9/27/17	Mon 11/6/17	
69	0%	📌	FinalProposal Report	29 days	Wed 9/27/17	Mon 11/6/17	
70	0%	📌?	Analytical analysis 2 Team Memo				
71	0%	📌	Individual Analytical Analysis 2	43 days	Wed 9/27/17	Fri 11/24/17	
72	0%	📌	Final Prototypes Summary	53 days	Wed 9/27/17	Fri 12/8/17	
73	0%	📌	Peer Eval 3 Due	56 days	Wed 9/27/17	Wed 12/13/1	
74	0%	📌	Final CAD Package and BOM	59 days	Wed 9/27/17	Mon 12/18/1	
75	0%	📌?	Final Propoal Revision				