Open Ended Wind Energy

Conceptual Design Report

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DISCLAIMER

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1 BACKGROUND

Introduction

Our project is open ended wind energy(13) and the wind turbine is used for converting the wind energy into electrical energy. The wind is used for rotating the turbine which produces the electrical energy by rotating in the magnetic field. There are wide ranges of horizontal and vertical wind turbines, Conservation of mass requires that air entering and leaving the turbine should be equal in magnitude. The maximum output power produced by the wind turbine is 59% of the air passing through the blades of turbine. Wind is a free of cost source for driving the turbine, so wind to rotor efficiency is a very important aspect affecting the final price of turbine. The dust particles on the blades and gears of turbine is one of the reason lowering the efficiency of wind turbine. Our goal for this project is to "Research and design a turbine for a grid scenario with a high contribution of renewables and be able to operate in an islanded mode"[8]. The client is asking us to design an electrical, mechanical and aerodynamic wind turbine that will be efficient enough to compete and possibly win the 2018 collegiate wind turbine competition. Furthermore, the project is open-ended meaning it is subjected to future changes allowing revision or additions to the project goals as the client see fit.

Project Description

The project client is Professor Willy and the expectations of the project are to execute the project successfully with high efficiency. In this way the project is required to have higher wind to electricity conversion capability. The energy in the wind propels the blades and produce the electricity.

Original System

The rotor is attached with the main shaft which rotates the generator for producing electricity. The extracted power is kept at a value more than the operating speed of theoretical power. There are three basic components of the horizontal axis wind turbine

- Rotor
- Generator
- Structural Support

The rotor is responsible for supporting the blades of the wind turbine and move under the influence of air. As the air strikes the blades of the rotor it starts to move. The generator is driven by the rotor of the turbine. The structural support is responsible for supporting the overall system.

2 REQUIREMENTS

This section describes all the the customer's requirements for the project. The client requires that we go to the U.S. Department of energy website and search for the 2018 collegiate wind competition follow the competition rules to generate the customer needs and build a wind turbine. These customer's requirements will then be translated into measurable quantifiable engineering requirement from which the goals of the project will be met.

2.1 Customer Requirements (CRs)

Here, all the customer requirements as asked by our client professor David Willy is refined and listed below as required. The table follows a format listing the customer requirements, number of needs, importance weighted score and the justification for each requirement. These CR's were generated from competition rules and design requirements provided on the collegiate competition website.

Table 1 No. of Needs, CR's, Importance, and Justification

No. of Needs	Customer Requirements	Importance	Justification
1	A working wind turbine	5	Per collegiate wind competition 2018 all competition participants need to create an effective mechanical, electrical, aerodynamic wind turbine
2	Turbine can produce energy with wind at 20m/s	5	The Collegiate completion rules specifies that the turbine design should be able to continuously withstand winds speeds at 20m/s.
3	Durable	5	The customer requires that the design must be durable in order to withstand damages or any hard-tearing from the competition testing and the through the period for which it is expected to last

4	Safe	5	Customer requires that all aspect of the wind turbine and load design should be safe for testing in an on-site wind tunnel
5	Working control system	4	Customer specifies that all created turbine designs must shut down when disconnected from the grid as well as manually as commanded
6	Load Design	5	A storage element device for bulk energy storage will be provided to the team by the competition judges at the competition day provided it would be used in a safe and reliable manner.
7	Turbine can fit via a 61cmX122cm door	5	Competition rules specifies that the Turbine should be capable fitting through a 61cm by 122cm door of the testing site.
8	Rotor and non-rotor parts must be contained in a 45X45X45cm cube	4	Competition rules requires that all rotor and non-rotor turbine parts must be contained in a 45cm by 45cm by 45cm cube centered horizontally on the flange axis with its horizontal mid-plane located 60 cm ± 3 cm above the mounting flange.
9	Reliable	4	Customer requires that the wind turbine performance should constantly be in good quality
10	Proper wiring	5	Competition rules specifies that all components must meet safety requirements including, but not limited to, proper wiring practices, shielding of hazardous components, and proper heat rejection.
11	Software testable	3	Competition rules requires that we are able to test design components and generates results of laboratory and/or field testing for the turbine prototypes.
12	Earth ground system (≤100kΩ)	3	To prevent overvoltage of the tunnel data acquisition system, turbine electrical system ground(s) must be electrically tied to this base

			plate with a 100 kΩ or lower resistance connection.
13	Turbine must be able to yaw	3	The tunnel base flange, where the turbine is mounted, will be subjected to yaw rates of up to 180° per second with a maximum of two full rotations from the initially installed position.

2.2 Engineering Requirements (ERs)

ERs are measurable physical quantities that a designer uses to meet the objective of the of the project. The engineer translates the CRs into ERs in order to solve the problem presented by the constraints set up by the stakeholders. It also specifies a standard system from which the project can be developed and properly managed. Table 2 below lists the engineering requirements, targets and the rational reasoning.

Table 2 ERs, Targets, and Rationale

Engineering Requirements	Targets	Rationale
Power density	0 - 700 W/m^2	To be able to achieve maximum power over the turbine face surface area.
Operating Voltage	5 volts	Competition rules requires a constant voltage of 5 volts to be running
Lift Coefficient	1.75	Needs to meet this requirement to be able to initiate the turbine spin.
Stability	30.0 kPa	Turbine pillar and rotor parts needs to be able to withstand a tensile stress 30.0 kPa
Product Dimension (Size)	≤ 45X45X45cm	Project dimension set up by competition rules
Drag Coefficient	≤ 1.00	The maximum drag coefficient should be lower than 1.00
Max Voltage Limit	120 VAC	Project dimension set up by competition rules
Load material	≤100kΩ	Load material should be able to contain a load power of 40W

Torque capacity	2 kN-m	To achieve an efficiency greater than 70 percent
Efficiency	>60%	Rotor and non-rotor parts needs to be able to meet a combine efficiency greater than 60%

2.3 House of Quality (HoQ)

This section presents a matrix format system called the House of Quality that translates the CRs into a suitable number of engineering targets (ERs) necessary to meet the expectations of the new design product. The matrix system relates all customer requirements as requested by the client and from benchmarking data collected to the newly established ERs. ERs and the technical difficulty shown on the HoQ are appropriately weighted on a scale of 1-5 relative to the degree of the constraints presented by the problem. Also, the relationship area is rated from 1-9 with 1 being the least important and 9 very important whereby the CRs meets the engineering set up target. This is the area where the performance is measured in attempt to better the design product. Once all ERs are ranked their total cumulative weights (importance rating) will identify what customer needs is very important to the design, the ones that needs improvement and those that needs to be changed. Figure 2.3 below shows the HoQ and all its representative components in an interrelationship matrix format.

Technical Requirements											
Customer Needs	**Customer need rank**	Power density	Operating Voltage	Lift Coefficient	Stability	Product Dimension (Size)	Drag Coefficient	Max Voltage Limit	Load material	Torque capacity	Efficiency
Working wind turbine	5	5		8	7	7	6			9	9
Turbine can withstand continuous winds at 20m/s	4.5			5	7	8		2			
Turbine can fit via a 61cmX122cm door	4					9					
All turbine parts must be contained in a 45X45X45cm cube	5				1	9					
An electrical control system	2		2								6
An electrical ground of ≤100kΩ	1										5
Proper wiring	1								9		3
Load design	2	7	3		2				9		
Safe	5		5							8	
Reliable	3			4	6				7	7	8
Durable	3.7	6							7		
Software testable	2			1			1				5
Specification Value		[W/m^2]	Volts [V]	Dimensionless	Strength [kPa]	meters [m]	Dimensionless	Volts[V]	[H],[kΩ],[C]	Newton-meter [N-m]	Performance [%]
Technical Difficulty (1-Low, 5-High)		5	3	1	2	1	1	5	4	3	5
Importance Rating		61.2	35	76.5	93.5	152	32	9	73.9	106	99

Figure - 1 House of Quality (HoQ) [8]

Based on the HoQ the most important CRs is the product dimensions while the least is the max voltage limit. This is however accurate as it is very important that the team creates a design with a product dimension size that will readily fit through the competition testing site to qualify the design and the team to begin the process of the competition. On the other hand the team will not necessarily get a penalty if maximum voltage limit is surpassed. In which case, the design power efficiency will be reevaluated to limit its maximum voltage or certain design targets will be added or changed to meet up with the competition setup standards. All other importance rating scores can be seen below the HoQ as they meets the needs of the client.

3 EXISTING DESIGNS

In this section, the team worked hard researching similar designs that will be providing us with more information about our project. This section will have three different existing designs that will be related to our project. The information we got will lead us to more creative thinking, and settle down on the best design.

3.1 Design Research

Through literature review, boats were being propelled along river Nile by wind energy in back in the year 5000 B.C. Coming to 200 B.C., vertical axis windmills having woven reed sails ground grains in middle east and Persia and China simple windmills pumped water (Lewis 2007).
American settlers used windmills in grinding corns and wheat, at sawmills in wood cutting and water pumping. Wind power was now employed in building lightening due to development of electric power. Wind electric turbine continued till the 1950s, but the existence of low energy prices and cheap oil sidelined it. The oil deficiencies of the 1970s changed the vitality picture for the U.S. also, the world. It made an enthusiasm for elective vitality sources, making ready for the reentry of the breeze turbine to produce power(Lewis2007) [2]. The turbines, bunched in substantial breeze asset territories, for example, Altamont Pass, would be viewed as little and uneconomical by present-day wind cultivate improvement models. Today, wind-controlled generators work in each size range, from low turbines for battery charging at separated living arrangements to vast, close gigawatt-measure seaward breeze cultivates that give power to national electric transmission frameworks.

3.2 System Level

After researching, the team found the three different designs, that related to our project. For sections 3.2.1 to 3.2.3 existing designs will be provided with a brief description of each.

3.2.1 Existing Design #1: Gearless wind turbines

Gearless breeze turbines completely got no gearbox. Preferably, the rotor shaft is installed straight to the generator where the blades move the same speed it spins. Lagerwey and Enercon have discovered gearless breeze turbines with independently electrically energized generators for a long time, and Siemens creates a gearless "upset generator"3 MW model while building up a 6 MW model. To compensate for a direct drive generator slower turning rate, the measurement of the generator's rotor is expanded so it can contain more magnets to make the req॰uired recurrence and power. Gearless breeze turbines are frequently heavier than equip based breeze turbines. An examination by the EU was known as "Reliawind" given the most prominent example size of turbines has demonstrated that the consistent quality of gearboxes isn't the primary issue in wind turbines. The dependability of direct drive turbines seaward is as yet not known since the example estimate is so little.
Gearless turbines have a lower cost of maintenance since there is no replacement of gearbox.

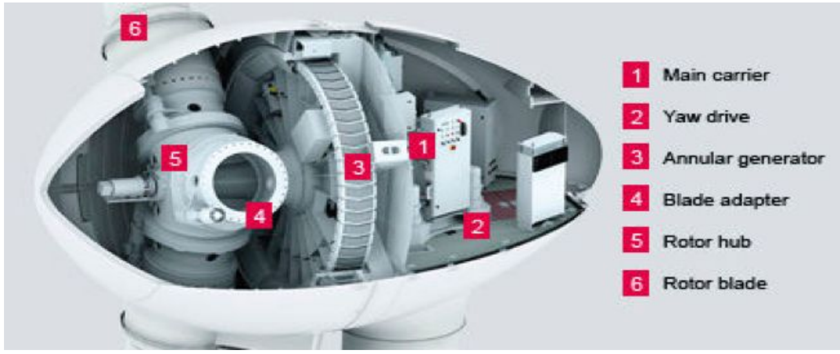

Figure 2 - Gearless wind turbine [3]

3.2.2 Existing Design #2: Turbine with gear

In traditional breeze turbines, the sharp edges turn a pole that is associated with a gearbox to the generator. For the generator to generate electricity speed of the blades is converted into gearbox by increasing the turning rate for example 14 to 18 to rotations each minute (Jonkman and Scott 2009)[4]. The utilization of attractive gearboxes has additionally been investigated as a method for decreasing breeze turbine cost for maintenance.
They produce more energy but have a high cost of maintenance in the replacement of gearbox when it breaks down.

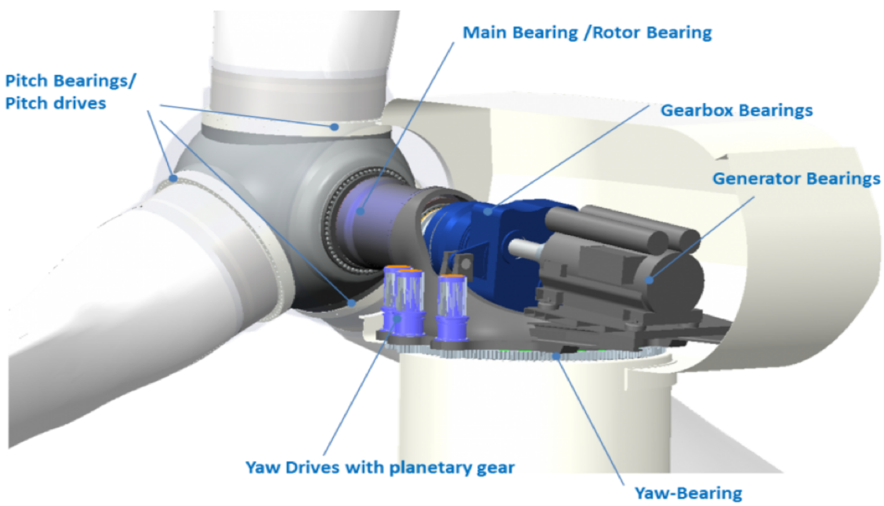

Figure 3 - Turbine With Gears [3]

3.2.3 Existing Design #3: Blade count

For system reliability, component cost and aerodynamic efficiency we need to consider the number of blades. Location of blades downwind or upwind of the tower together with speed of rotor affects noise emissions. A minimal rise in tip speed could make a huge difference in noise emission from the trailing edges of the blade (Jonkman and Scott 2009)[4]. This a three blade breeze turbine. Its most preferred as it produces high level of energy.

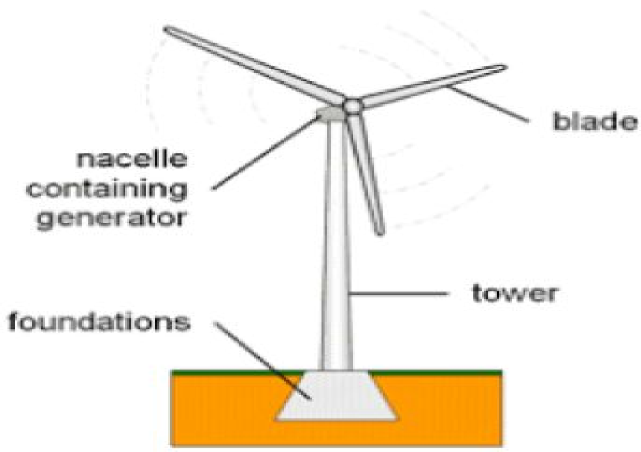

Figure 4 - Blade Count [5]

3.3 Functional Decomposition

The functional decomposition of turbine is shown in figure - 4

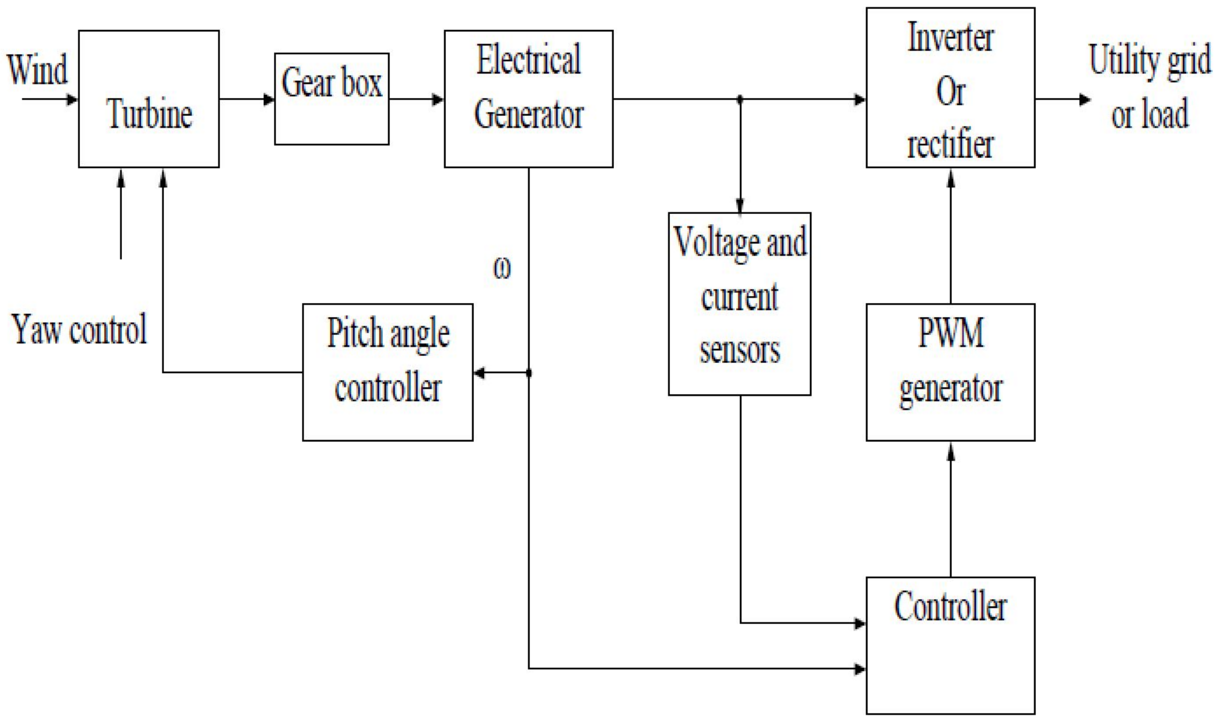

Figure - 5 Functional Decomposition

From this figure we can see that the function of the wind turbine is divided among various blocks. The wind is input to the turbine block which moves the electrical generator with the help of a gear box. There is a pitch angle controller directly attached with the electrical generator for the control of amount of electricity produced by the generator. The electrical energy produced by the generator is fed into inverter system for inter conversion of A.C and D.C quantities.

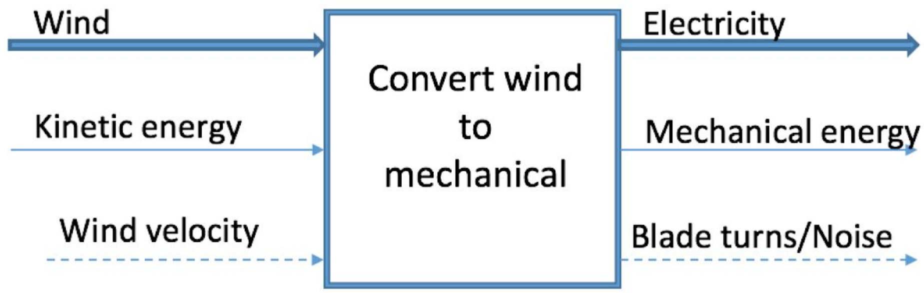

Figure - 6 Black Box

We can see that the basic purpose of the block is to convert the wind energy to mechanical energy. The input to the block is wind which produces the kinetic energy and velocity in the turbines. The output from the block is electricity, mechanical energy and Blade/turns Noise. The conversion from the input parameters to output parameters is brought by rotor and generator. Once the generator starts rotating the kinetic energy gets converted into electrical energy. This is the way wind turbine is performing the inter conversion.

3.4 Subsystem Level

There are some of the subsystems for this project, and for these subsystems different existing design are present so in this section few existing designs are describing for the subsystem.

3.4.1 Subsystem #1: Blade

Blade is using the fan of turbine which will rotate with the help of air, and there are different kind of blades already made.

3.4.1.1 Existing Design #1: Curved Blade

One of the most effective blade shape is curved blade which uses in wind turbines, these blades cut the air easily and these can move in the presence of low air pressure as well because of their curved design. This design can use for our project because curved blades are good to use for rotating the turbine system.

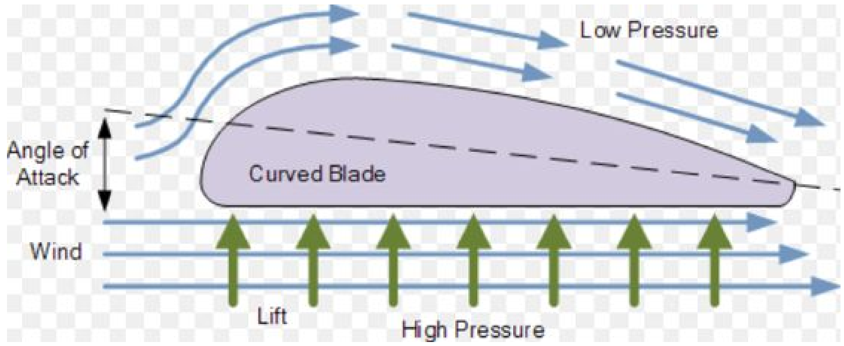

Figure 7: Curved blade

3.4.1.2 Existing Design #2: Round Blade

Another design for the blade is round blade which has curved shape as well but it has round shape from the start and it is thin in their width as well. This type of blade can also use in our project because of their better performance as the design is showing in the following figure.

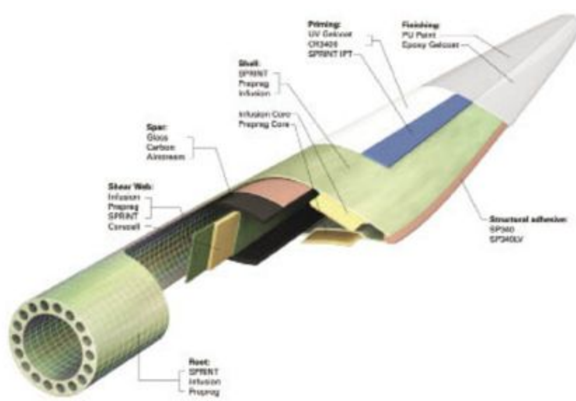

Figure 8: Round Blade

3.4.1.3 Existing Design #3: Straight Blade

This is the straight shape blade which has no curve and no round body. This blade is difficult to use because its design has less capability to cut off the air therefore need high pressure air to move the turbine. Following figure is showing the design of straight blade.

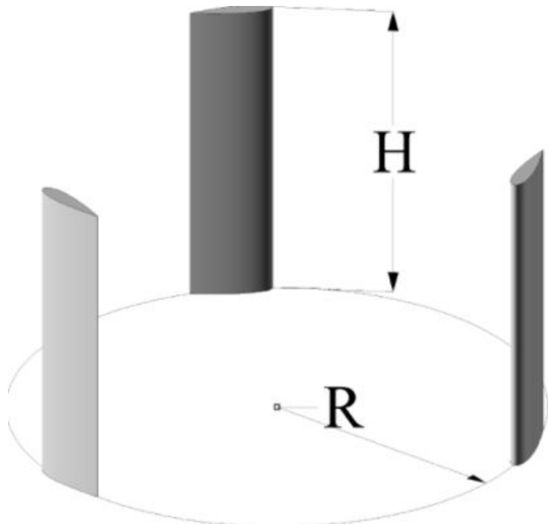

Figure 9: Straight Blade

3.4.2 Subsystem #2: Tower

As the blade stand over the tower so tower is another important subsystem for this project and its existing designs are presenting below

3.4.2.1 Existing Design #1: Lattice Tower

In this design of tower a zigzag body has made in the tower to make it strong and capable of bearing the high pressure air without dangling down or topple over. This design can use in the project when the blades are heavy and long. Design is showing in the following figure.

Figure 10: Lattice Tower

3.4.2.2 Existing Design #2: Pole Tower

A pole tower is the one which is using in regular wind turbines as it is slim and capable of bearing high pressure air as well. It can use in our project also because of its slim body. Design is showing below

Figure 11: Pole Tower

3.4.2.3 Existing Design #3: Guyed Mast

Guyed mast is the design in which a straight stand uses and it holds with the strong wires which dig into the ground and hold the tower. This design is also useful as it has the capability to stick in strong air pressure. Design is showing below

Figure12: Guyed Mast

3.4.3 Subsystem #3: Gearbox Bearings

As the turbine produce electricity on the basis of speed so variation of speed is present in the turbine using the gearbox which rotates the gears according to the air speed. So the subsystem is different bearings.

3.4.3.1 Existing Design #1: Steel Bearings

Steel bearings are strong and non-rust bearings and these can use for high speed shifting of gears without getting stuck. Design of steel bearings is showing below

Figure 13: Steel Bearings

3.4.3.2 Existing Design #2: Iron Bearings

Another bearings available in the market and these iron bearings, these bearing are useful but they get rusty after sometime when didn't treats properly. As showing the design in following figure

Figure 14: Iron Bearings

3.4.3.3 Existing Design #3: Aluminum Bearings

Aluminum bearings is another existing design for the bearings, and these are useful for light weight but they cannot hold strong force but the advantage is that it doesn't get rusty as well. Design is showing below

Figure 15: Aluminum Bearings

4 DESIGNS CONSIDERED

The possible designs that were anticipated were chosen from previous competition archives. The archives included the 2014 to 2017 Collegiate Wind Competition. [ ] The Competition is a competition event that involves highly innovative designs that surpassed technical leaps and bounds in the basis of collegiate competition. Analyzing the designs in previous competitions gave us the capability to develop our final design selection based on the CR and EG of the House of Quality. The comparison between these concepts generated a final design selection and enhancements of the design.

4.1 Design #1: Vertical Axis Wind Turbine

The vertical axis wind turbine was a design that was considered. The vertical axis was a significant idea because the apparatus did not need the yaw system to the direct the blades towards the wind. The other characteristic is that there are fewer components that need to control yaw and pitch.[1] The disadvantages to this design that the stability of a design is not available. The forces that are acting on the vertical axis wind turbine are more turbulent. [1] This particular design is found in urban locations and on roof tops.

4.2 Design #2: Vertical Axis Wind Turbine (flat blade)

This vertical axis wind turbine consists of the same components that are consistent with the typical VAWT. The vertical wind turbine design in this category has blades that are flat in design selection. The flat blades are placed at an angle that will catch the wind from any direction. The advantages and disadvantages are similar to the previous design. The only drawback to this design is that it is less efficient than the typical vertical wind turbine. The VAWT does not have the blades that are contoured from bottom to top in reference to the attachments. The blades simply attached to a middle beam and stand 90 degrees to the base. The team have considered parts of this design and see the functionality in simple geometry. This design would be inefficient for large production of energy because of the instability of the blades and tower. The VAWT is only used in urban locations that have less volatile wind speeds. [9]

4.3 Design #3: Horizontal Axis Wind Turbine

The horizontal axis wind turbine (HAWT) is a design that was most successful in reference to the customer requirements and engineering requirements. The design solution we have considered is to incorporate a recharging station to our wind turbine. Students of NAU will b able to attach their USB to the base of the wind turbine to recharge their small electronic devices. The HAWT is a design that is capable of withstanding high wind shears that incorporate higher efficiencies. The high towers are placed in strong winds which are able to increase the speed of the blades by 20% and power output of 34%. Figure 11 in the appendices show the several design that were considered for the final project. The design C is the design that could be incorporated in our final design. [9]

4.4 Design #4 - 10: Additional Designs in Appendices

The additional designs that were considered are listed in the appendices listed as Designs Considered. The designs that are located in this section are possibilities from the CR and ER constraints. The designs range from vertical wind turbine designs to the horizontal wind turbine. There designs that were developed from existing designs. An example would be the design from Northern Arizona University. In 2016, a HAWT design was created and then components were added to enhance the capabilities of the design.

The components that were added are the yaw control, electronics control, and stopping mechanism. These were added to create a more efficient design that will capture the effectively through yaw controls.

5 DESIGN SELECTED – First Semester

In this chapter it will show you the reasons behind what made the team choose design C. After doing more research about the projects on the collegiate wind competition website, and the research process led us to settling on design C.

5.1 Rationale for Design Selection

Figure - 16 Selected Design C

This is our selected design for our project, where as shown in table 3 in the Appendix A, design C is a complex design with a simple working, blade design and a good yaw to help the turbine to rotate. Even though it cost alot, but it has a good reliability and efficiency and this is why we have chosen it as our selected design. We are thinking to use electric plug or USB to power up the turbine in order to generate electricity as you can see in figure 7.

10 REFERENCES

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11 APPENDICES

11.1 Appendix A: Pugh Chart

Table - 3 - Pugh Chart

TOTAL	Efficiency	Manufacturability	Reliability	Cost	Blade Design	Yaw	Working	Complexity	Design Concepts
-3	S	-	+	-	-	S	S	-	Design F
-5	S	-	-	-	-	S	S	-	Design E
-4	S	-	S	-	-	S	S	-	Design D
+1	+	S	+	-	S	+	S	-	Design C
0	S	S	S	S	S	S	S	S	Design B (Datum)
-6	-	+	-	-	-	-	-	-	Design A

Pugh Chart

11.2 Appendix B: Decision Matrix

Table 4 - Decision Matrix

Criterion Weight		Design A		Design B		Design C		Design D		Design E		Design F	
		Raw Score	Weighted Score	Raw Score	Weighted Score	Raw Score	Weighted Score	Raw Score	Weighted Score	Raw Score	Weighted Score	Raw Score	Weighted score
Complexity	0.10	100	10.0	90	9.00	80	8.00	40	4.00	60	6.00	50	5.00
Working	0.10	0	0.00	80	8.00	90	9.00	70	7.00	70	7.00	70	7.00
Yaw	0.15	0	0.00	0	0.00	100	15.0	0	0.00	0	0.00	0	0.00
Blade Design	0.10	50	5.00	100	10.0	100	10.0	40	4.00	70	7.00	40	4.00
Cost	0.15	100	15.0	90	13.5	80	12.0	50	7.50	70	10.5	70	10.5
Reliability	0.15	0	0.00	50	7.50	100	15.0	60	9.00	70	10.5	60	9.00
Manufacturability	0.10	60	6.00	80	8.00	70	7.00	60	6.00	80	8.00	70	7.00
Efficiency	0.15	0	0.00	60	9.00	95	14.25	60	9.00	70	10.5	60	9.00
Totals	1.00		36.0		65.0		90.25		46.5		59.5		51.5
Relative Rank			6		2		1		5		3		4

Decision Matrix

11.3 Appendix C: Designs Considered

Figure 17: Vertical Wind Turbine with angled blades [1]

Figure 18: Vertical Wind Turbines with 90 degree blades [6]

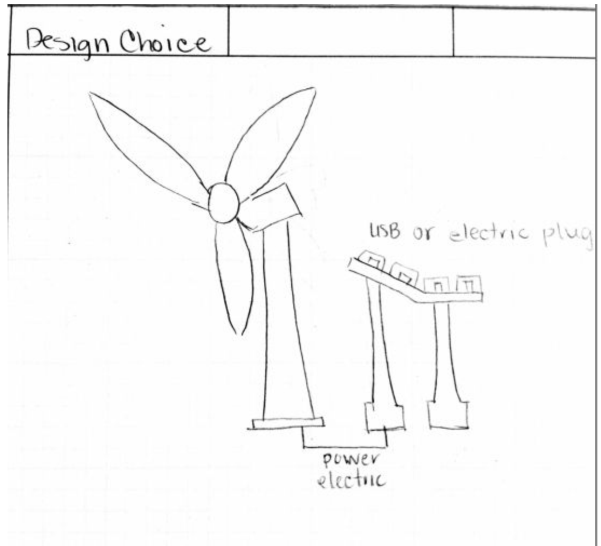

Figure 19: Design choice with electric power plug in tower

Figure 20: Primus Wind Power Turbine [10]

Figure 21: Sunforce 44444 Wind Turbine [11]

Figure 22: Tycoon Power Systems TPW 400 DT [12]

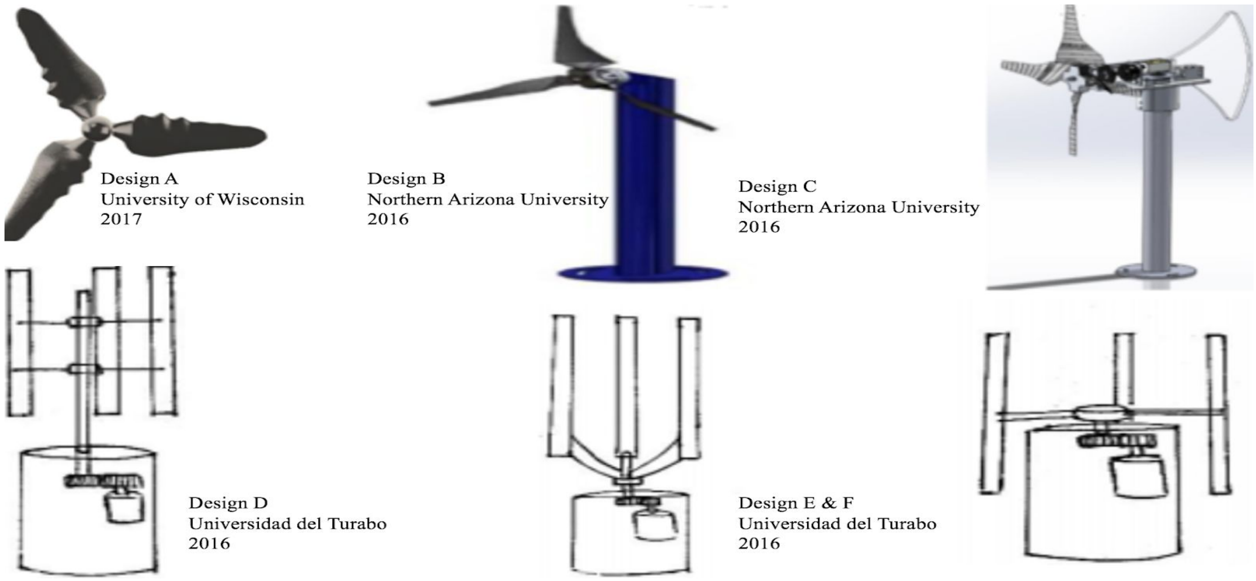

Figure 23: Designs from Collegiate Wind Competition [7]