Micro-Wind Turbine Design

Background Report

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1 BACKGROUND

1.1 Introduction

Since the 19th century, the wind turbine has been a prominent part of electric generation. Its importance in green energy relates to the fact that because wind energy requires no additional fuel sources and does not have harmful byproducts, wind energy is for the most part pollutant-free. Additionally, wind turbines are significantly less expensive than other means of capturing energy (i.e. a dam).

The purpose of this project is to design, build, and test an updated version of the previous ISES micro-turbine. The project is sponsored by Professor David Willy. Professor Willy performs research for the Institute for Sustainable Energy Solutions (ISES). He has professional experience both in renewable energy and in wind turbine design. Because the project will ultimately be tested at ISES, both ISES and Professor Willy are the stakeholders for this project.

1.2 Project Description

Following is the original project description provided by the sponsor:

> Design, Build, and test a version 2 of the ISES micro- turbine. This turbine is to be used as a future test bench to test state of the art control algorithms and a bridge to future designs. Further iteration after testing is expected (and encouraged) of key components that warrant iteration by the end of the project in order to meet the design requirements below.

1.3 Original System

This project involves the redesign of the previous year's turbine model. In order to create a more efficient turbine, we analyze this model.

1.3.1 Original System Structure

The original wind turbine consisted of three blades composed of carbon fiber. These blades were mounted to the housing, or nacelle, with a single hub tightened by a small bolt and a few washers. The nacelle was a support structure for the rotor, hub, gearbox, generator and yawing system. This system was connected to a tower composed of three six foot long threaded of aluminum alloy. Conclusively, the tower was mounted to a base constructed from sheet metal with dimensions of 20x18x19 inches.

1.3.2 Original System Operation

The original wind turbine design operated in a downwind setup. That is, the turbine faced away from the wind direction. The wind turbine used a passive yaw system that allowed the blades to capture more wind for better power production. The nacelle, which houses the main wind turbine components, was used to reduce inefficiencies as the air flowed over it and onto the blades. The turbine blades then rotated due to lift, which is dependent on the angle of attack. In turn, this momentum rotated an internal shaft, which was connected to a gearbox, increasing the rotations per minute on an adjacent shaft. This final shaft then powered the generator.

1.3.3 Original System Performance

The cut-in wind speed for the turbine was 14.2 m/s with the nacelle in place and 10.2 m/s without. The maximum rotor speed was 18 m/s. The maximum rotations per minute at a wind speed of 17 m/s were 4000 and 5661 with and without the nacelle, respectively. The turbine is able to yaw regardless of the angle of wind impact.

1.3.4 Original System Deficiencies

One of the downsides of the original wind turbine was that because of its downwind design, boundary layers formed as the wind approached the blades, thus requiring a higher cut-in wind speed and resulting in lower rotations per minute by a factor of 1.415. Consequently, the start-up wind speed is extremely high, considering that the turbine is unlikely to see wind speeds higher than 4 m/s in most operating environments.

2 REQUIREMENTS

The project goals are divided into customer requirements and engineering requirements. Customer requirements consist of the specification set forth by the client, such as: safety in operation, portable systems, cost-efficiency and ease of use. Many of these specifications are then translated into engineering requirements, where calculable variables are described.

2.1 Customer Requirements (CRs)

The customer requirements are listed in order of decreasing importance in **Table 1** below. The most crucial specification is that the wind turbine be safe to operate. This stems largely from the fact that in the previous year's competition, there was a turbine where, due to inadequate durability, the blades tore off of the rotor and became hazardous projectiles. Because the project is of micro-design, it is necessary that the turbine be lightweight enough to be carried by a single person.

Needs	Descriptions
1. Is safe to operate	Is not a hazard to people near the turbine
2. Must be portable	Product can be moved by one person.
3. Creative design	Design must be innovative
4. Is easy to use	Could be operated by new users
5. Must have low wind cut in speed	Able to utilize 3-10 m/s wind speed range power output.
6. Must be able to power a 5V load	Must be able to power a 5 volt load
7. Must be reliable	Can be used multiple times without failing
8. Exhibits durability	Can withstand harsh wind tunnel conditions
9. Easy assembly	Easier user operation and assembly than previous design.
10. Exhibits stability	Must not sway in the wind, or fall over

Table 1 – the list of customer requirements

2.2 Engineering Requirements (ERs)

The system has been dissected to all of the variables that will ultimately satisfy the customer requirements. These variables are shown in **Table 2**. Although no experimental decisions have been made as of this stage in the design process, the variables have been laid out to set up the next stage in design.

Requirement	Description
1. Rotor Diameter	Diameter of the circular area covered by the blades
2. TSR	Tips Speed Ratio, the ratio of the rotational speed of the blade tips to the free stream speed of the wind
3. Cp	Coefficient of performance, how much power that the product can take out of the wind
4. Weight	Weight of the entire turbine
5. Yield limit	Force per area at which the materials used in the turbine will yield
6. Modulus of Elasticity	Constant of proportionality of stress to strain of a material
7. Rated Power	Rated output power of the generator
8. Shear	Force caused by viscous forces, parallel to the surface
9. Footprint	Area covered by the base of the turbine
10. Chord Length	Length of leading to trailing edge of air foil

Table 2 – engineering requirements based on customer specifications

2.3 House of Quality (HoQ)

To better understand the relationship between the customer and engineering requirements, our team has constructed a house of quality. **Figure 1** below rates the customer requirements according to importance then presents the variables that would be used to satisfy these requirements.

Customer Requirement	Weigh	Rotor Diameter(m)	TSR	Weight(kg)	Yield Limit (Mpa)	Modulus of Elasticity	Rated Power(V)	Sheer(MPa)	Footprint	Cp	Cord Length(m)
1. Is safe to operate	40			5	10	10	5	5	5		
2. Exhibits durability	40				20			20			
3. Exhibits stability	40			10	10	10		10			
4. Power a 5V load	40		10				10			10	
5. Low cut in wind speed	40	10								10	20
6. Must be reliable	30				10	10		10			
7. Must be portable	20			10					10		
8.Creative design	LTE										
9. Easy to use	LTE										
10. Easy to assemble	LTE										

Figure 1 – the link between customer and engineering requirements (House of Quality)

3 EXISTING DESIGNS

Three design innovations used in benchmarking and idea generation are: the Dragonfly wind turbine, Robert Howell's design and the MagLev wind turbine.

3.1 Design Research

In order to thwart unintentional theft of design ideas, while allowing room for our own innovations as mechanical engineers, our team has analyzed the following systems with specific aspects in which they excel in mind.

3.2 System Level

The Dragonfly Wind Turbine's blade and nacelle design allow it to operate at wind speeds as low as 2 meters per second, a crucial part of micro-wind turbine design [1]. Robert Howell's turbine similarly operates at low winds speeds. These turbines are horizontal-axis wind turbines (HAWT) and vertical-axis wind turbines (VAWT), respectively. Because both types of turbines operate with high efficiency, our design team has the freedom to choose whether to design a HAWT or VAWT without efficiency consequences. Lastly, the MagLev Wind Turbine uses magnetism to suspend parts of its system, thereby eliminating frictional effects.

3.2.1 Dragonfly Wind Turbine

Professor Akira Obata of Nippon Bunri University's wind turbine design includes what is known as dragonfly wings. The key feature of this turbine is that it can operate at speeds as low as 2 m/s, which as an ideal value for a micro-wind turbine. [1]

3.2.2 Robert Howell

Professor Robert Howell of the University of Sheffield designed a VAWT using an H rotor. It has a wing tip speed ratio (TSR) of 2.2 at a wind velocity of 5.45 m/s, yielding an efficiency of 0.225. Even at wind speeds as low as 3.16 m/s, the wind turbine has an efficiency of 0.135. [2]

3.2.3 MagLev Wind Turbine

The MagLev wind turbine was designed by NuEnergy Technologies. It is a vertical-axis wind turbine that operates with a magnetically levitated system. The system is wear-free and has frictionless components, which is an objective our project should aim for to maximize power production. Traditional wind turbines tend to wear down easily, causing damage to the system as extensive as the blades ripping off during operation. For this reason, it is essential we design with durability in mind. [3]

3.3 Subsystem Level

The Dragonfly Wind Turbine does not have the ability to yaw, but has wings designed to allow startup speeds as low as 2 m/s. Robert Howell's design demonstrates a high efficiency for micro-wind turbines, and the MagLev Wind Turbine uses magnetism to eliminate frictional components. These aspects are analyzed in further detail as follows.

3.3.1 Blade System

Of the three designs outlined, the Dragonfly turbine has the most technically and aesthetically impressive wing design.

3.3.1.1 Dragonfly Wind Turbine

The highlighting component of the Dragonfly wind turbine are the dragonfly-inspired blades. The shape of the blades and composition of carbon and polycarbonate materials allow it to operate at wind speeds as low as 2 m/s. Technical advantage aside, the transparent panels in the blade are designed to show the carbon structure inside. [1]

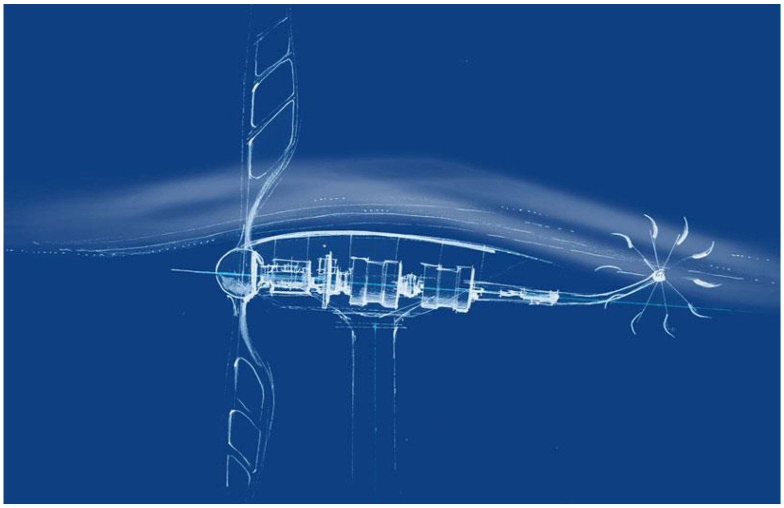

Figure 2 – the Dragonfly wind turbine profile

3.3.1.2 Robert Howell

The NACA022 profile is integral to Howell's design. It is based on a thickness of 22 mm and a resulting chord of 100 mm. The height is approximately 400 mm. The blades have an aspect ratio of 4. The turbine has a solidity of 1.0 for three-bladed design and 0.67 for two-bladed design. These blades are constructed using a CNC milling machine from a high-density foam. It is necessary that these blades maintain a high thickness to withstand the high centrifugal bending forces due to the rapid rotation of the turbine. [2]

3.3.1.3 MagLev Wind Turbine

The vertical-alignment of the blades in the Maglev turbine allow it to capture greater surface areas during startup. Unfortunately, this design ultimately results in an increased drag coefficient.

Figure 3 – the MagLev turbine design

3.3.2 Nacelle

A nacelle is necessary for a horizontal-axis wind turbine but an obstruction to a vertical-axis wind turbine. The only design we researched that includes a nacelle is thus the Dragonfly wind turbine. This design in particular is discussed in the ways that it is beneficial to energy capture.

3.3.2.1 Dragonfly Wind Turbine

The nacelle is designed to replicate an airfoil. This results in the wind velocity increasing as it passes through the system, which adds rotations per minute to both of the blade systems on at the front and rear of the turbine. A similar design for our project's nacelle would aid in startup at low wind speeds by providing a means of accelerating these wind speed.

3.3.2.2 Robert Howell

As a vertical-axis wind turbine, this system does not required a nacelle. It does, however, have a simpler structure than a horizontal-wind turbine. Moreover, the generator and gearbox can be placed near the ground and improve accessibility for maintenance.

3.3.2.3 MagLev Wind Turbine

The system is a vertical-axis wind turbine. Like Howell's design, it does not have a nacelle. In deciding whether our team should design a vertical-axis or horizontal-axis wind turbine, we can consider that with vertical-axis there would be one less component to design, allowing to spend more time focusing on the blades and the generator parts of the system.

3.3.3 Yawing System

A yawing system allows for a turbine to change direction based on the angle of attack of the wind. Of the systems we researched, none of them include yawing capabilities.

3.3.3.1 Dragonfly Wind Turbine

Although the Dragonfly turbine does not have a yawing mechanism, which is required for our project, it is noteworthy that the system does replace this opportunity with innovation. Rather than having a tail for yawing, the turbine has another horizontal axis turbine at the rear of the housing rotated ninety degrees relative to the first turbine. This secondary turbine also links up to a generator and accounts for some of the irreversibilities in the overall system. Similarly, our system can be designed to try and account for as many irreversibilities as possible and maximize power production at low wind speeds.

3.3.3.2 Robert Howell

The system is a vertical-axis wind turbine and thus does not need to yaw but rather benefits from having variable angles of attack.

3.3.3.3 MagLev Wind Turbine

Because the system is a vertical-axis wind turbine, the system does not need to yaw as it captures wind for all 360 degrees of rotation.

4 REFERENCES

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