Improving Wind Wonders

New Mexico Super Computing Challenge

Final Report

April 2, 2014

Team 77

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1. **Executive Summary**

The need for energy is ever growing in the Land of Enchantment. The wind turbine is a secure, alternative from other energy producing source to meet the demand. The fuel to power wind turbines is free and the energy produced from wind turbines does not the hurt the environment. However, the cost of wind energy is not as cheap as non-renewable energy that damages the environment as is the cost of creating and testing wind turbine designs is high. The time consumed in testing a wind turbine is also incredible. This program will help predict the wind turbine energy output based on the variables imputed into the program. The program will not only save material, time, and money but it will also help engineers and scientists improve wind turbine designs.

2. Introduction

2.1 Brief History of Wind Technology

People have harnessed the wind's power for a long time to advance civilization. Harnessing the wind's power began back in 5000 b.c where the Egyptians used the wind's power to help move boats across the Nile River. In 200 b.c, the Chinese created windmills to pump water while Persia and the Middle East made verticals axis windmills to grind grain (“History of Wind Energy”). Eventually, windmill technology spread into Europe during the 11th century where the Dutch developed their own version and used windmills to drain water out of the Rhine River Delta (“History of Wind technology”). When the Europeans began to migrate to America in the 19th century, the Americans happily accepted this old, conventional technology as their own and used windmills to pump water into ranches and farms.

Ohioan Charles Brush invented the first American Wind Turbine in 1888 (Ostrander). The Wind Turbine had a seventeen meter blade diameter and could only make 12 kilowatts at its maximum. Brush's wind turbine had 144 blades on it compared to today’s three bladed wind turbines. Public interest in wind technology was abandoned when steam engines, faster and cheaper alternative of energy, came along in the 1930's. Europeans replaced the old windmill for steam engines to pump water while Americans used the steam engine to create electricity (“History of Wind technology”). Despite the steam engine's popularity, wind technology was developing. Between the 1920's and 1950's is where people began to see the modern three blade wind turbine (Ostrander). During the OPEC crisis, when the Middle East decided to stop selling the United

States oil, wind technology's popularity grew in response for demand in electricity. In the 1970's scientists began to develop modern wind turbine methods such wind farms and the utility grid ("History of Wind Technology").

Today, the wind turbines currently used in New Mexico have a diameter of 101 meters and produce 2,300 kW output.

2.2 Wind Energy Fundamentals

The location of a wind turbine is very important because the geographical obstacles determine how a wind turbine should be designed (its limitations and requirements) and also how a wind turbine will function. An area with a lot of space is the ideal location for a wind turbine. The area must have a lot of space because the blades must have room to spin. Places like cities or forests create too much turbulence thus causing wind turbines to wear out faster (WindWise Education). The location also must have three of the following things: the right amount of wind available, the right amount of wind speed, and the mass of air in the location (Kalmilkov). Wind availability is important because there needs to be wind to turn the blades of the wind turbine (Kalmilkov). The wind speed is crucial because if there is too little, the wind turbine will not to generate electricity. If there is too much wind in area then the wind turbine could get severely damaged. The air mass determines how much pushing force the wind will have against the blades (Kalmilkov).

There are two important equations to keep in mind. One of them is the wind power. The wind power equation gives out how much power can be made by the wind turbine in an hour. The wind power equation takes into consideration the wind foil area, the wind's velocity, and the air density (Kalmilkov).

$$P = \frac{\rho A v^3}{2}$$

The other equation is the power coefficient. The power coefficient tells how much wind energy can be extracted from the wind turbine from how much total energy there is in the wind (Kalmikov).

$$C_p = \frac{P_t}{P_w}$$

There is a limit to how much power can be extracted from the wind and that limit is the Betz limit. The Betz limit was created by German physicist Albert Betz in 1919 where he concluded that wind turbine could not reach above of a power efficiency of 59% ("Wind Turbine Power Calculations"). Betz limit is applicable to all wind turbine designs.

$$C_{p_{max}} = 59\%$$

2.3 Wind Turbine Technology

While there are many parts of the wind turbine, it could be divided up into three main sections: the blades, the gearbox and the generator. These three main are what affect the wind turbine the most.

2.3.1 The Wind Blades

The wind blades capture wind's energy to create electricity by spinning the low speed shaft. This only works because of Bernoulli's principle.

$$P_1 + \frac{1}{2} {v_1}^2 \rho + \rho g h_1 = P_2 + \frac{1}{2} {v_2}^2 \rho + \rho g h_2$$

What Bernoulli's principle states is that the faster a fluid is moving the less pressure the fluid has (WindWise Education). Wind blades apply Bernoulli's principle by traditionally having blades that shaped like a half tear drop. Since the wind will have to go over both sides of the wind blade, part of the air will go over the longer side of the blade and the other part will flow underneath the shorter side. The wind blade will then turn due to the uneven pressure on each side where the side with greatest amount of pressure will push the wind blade (WindWise Education).

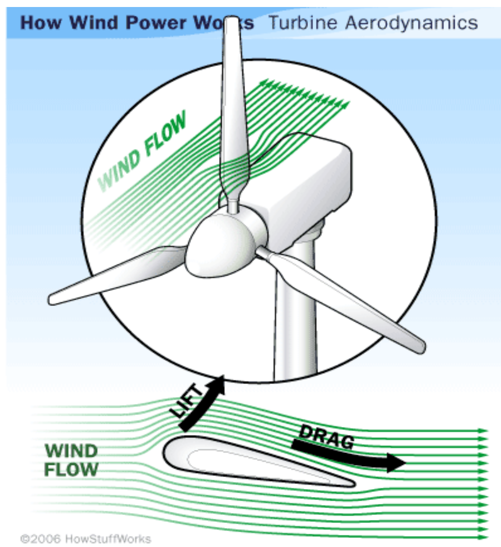

Fig.1 Shows how the lift and drag force affects the wind blade. (Layton)

The tip-speed ratio (TSR) is another crucial area of wind blade design. The tip speed ratio (TSR) is a ratio that calculates how fast the tip of the blade is going compared to the speed of the wind ("Wind Turbine Power Calculations"). Engineers use the ratio to help match the correct amount of blades to the generator. The wind blades should be designed to work with the generator but be optimized to work under the circumstances of its location.

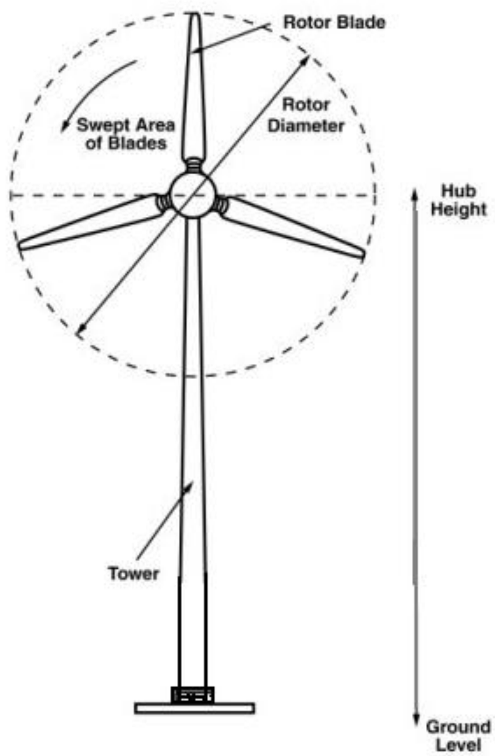

Fig.2 demonstrates how the rotor blades affect

The Sweep Area (Moleab)

One last thing to keep in mind is the lift-drag ratio. The lift-drag tells how much lift there is compared how much drag there is on the wind blades. It is crucial that there is more lift force than there is drag because the drag will not only slow down the wind turbine but will create turbulence which will ruin the wind turbine (WindWise Education).

2.3.2 The Gearbox

The energy transfers from the low speed shaft to the gearbox. The gearbox increases the rpm (rotations per a minute) from 30 to 60 rpm to about a 1000 since that is how much rpm is required for the generator to begin generating electricity (Layton). The gearbox increases the speed of the gearbox ratio. The gearbox ratio is the ratio between the speed of the bigger gear and the speed of the smaller gear(. The gearbox ratio works since centripetal force requires the gears meet up at the same time, the larger gear will move at a slower pace than smaller gear since it has longer distance to go and the smaller gear will go at a greater speed since it has a shorter distance to go (Layton). The smallest gear will lie at the end of the high speed shaft and transfer of all of its speed on to it. The gearbox ratio needs to be adjusted to allow the blades to have a strong amount of force but maintain the rpm.

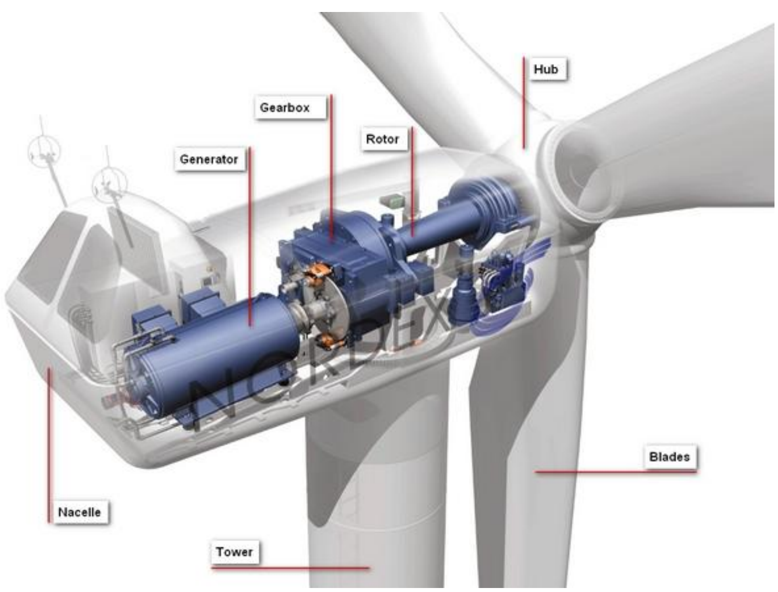

Fig 3. The essential parts of the Wind turbine *(*Analyseren, Concluderen en Adviseren).

2.3.3 The Generator

The generator is what transforms the wind's kinetic energy into electricity. The generator creates electricity by having the high speed shaft spin a group of permanent magnets around a copper wire. This motion creates voltage in the copper wire. The voltage then drives an alternating current down the tower to the grid (Layton) .The generator is what creates the power, so it should be the focus of how one should design the blades. The blades and gearbox combination must be able to manage to run the generator to its maximum capacity.

2.4 Wind Energy Costs

The fuel for Wind Turbines is free considering the fuel to make wind energy is wind. Wind energy production also does not pollute the environment and is a renewable resource. Unlike coal that is predicted to run out in 250 years or oil that is predicted to run out in 50 years. The upfront cost of a Wind Turbine though is expensive nor do wind turbine produce as much usable energy as a nonrenewable resources such as coal. The effort in designing a wind turbine and testing the parts of a wind turbine is long and tedious work. On average, it takes four to six months to test a wind turbine blade to see if whether blade is strong enough to stand up to wind. Wind turbine designers test the blade up to six million times during those months (Oakes and McNerney).

How Expensive is Wind-Generated Electricity?

	One-Time Cost per kW	Capacity (usage) Factor	Fixed Cost per kWh	Variable Cost per kWh	Total Cost per kWh
Gas Turbine	$439	15%	5.2¢	8.7¢	13.9¢
Coal	$1,338	90%	2.7¢	1.9¢	**4.5¢**
Nuclear	$2,180	90%	4.3¢	0.3¢	4.6¢
Wind	$1,254*	30%	7.5¢	0.0¢	**7.5¢**

The one-time, installed cost of wind seems to be up closer to $1,900 in 2011, compare with these estimates from about 2006.

Fig 4. Compares the cost of wind energy compared to nonrenewable materials.(2006, zfacts.com)

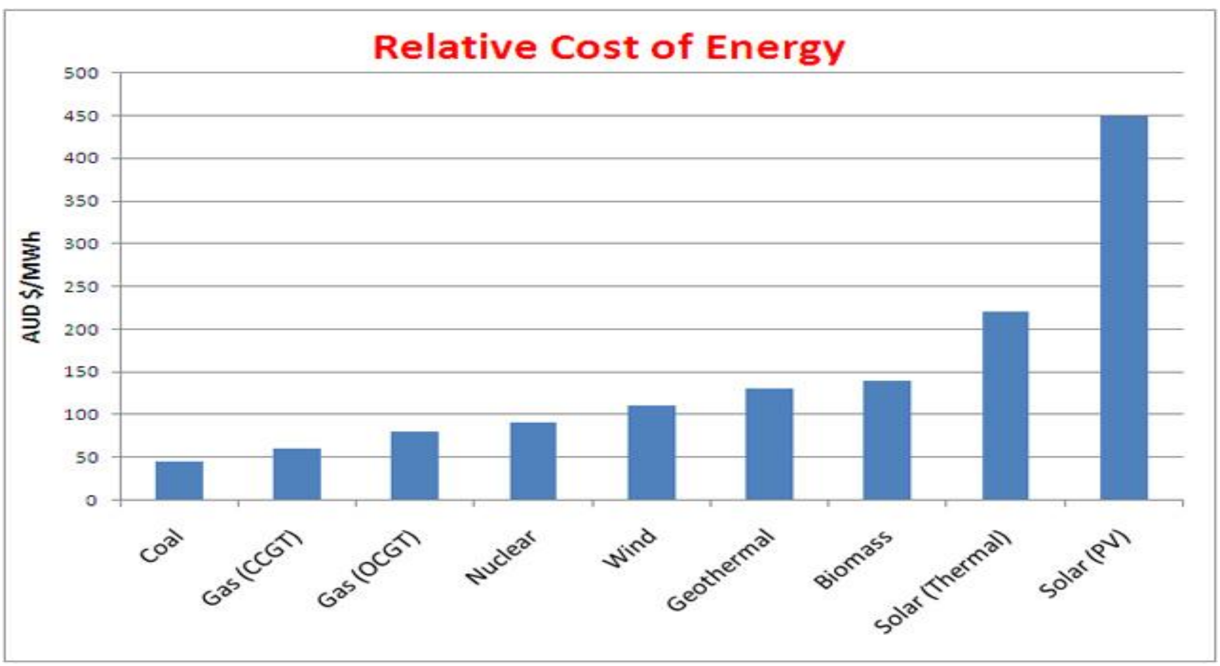

Fig 5. Compares the cost of Mega Watts produced by wind energy to both renewable and nonrenewable resourses.(Fallet)

3. Problem Statement

More than of half of the world's energy comes from nonrenewable resources that will hurt the environment. Also, these nonrenewable resources will be depleted soon. Another alternative to these nonrenewable resources is wind energy. However, wind energy technology is very expensive and takes a lot of time to test the individual parts of wind turbine. This time can be used to go straight to installing the wind turbine instead. Wind energy does not produce as much usable energy (electricity) as nonrenewable resources. It is a better for the wind turbine engineers to use a program that will test each part that affects the wind turbine energy output the most than to waste time and resources. Our hypothesis is that the program's results will correlate with the data that major wind energy companies have collected off their wind turbines and see if those wind turbines can produce more energy in New Mexico.

4. Methods

The Data that was used to test the program was not ours but came from major companies. The major companies were Mitsubishi of Japan, General Electric from the United States, and Vestas of Europe. By using data from three different companies all from the three different continents allowed us a world view of different wind turbines and how each was fitted for its location. The data also allowed us to test different wind turbines from different countries. This allowed us to observe the estimated power outputs in different locations. Using this information we came up with the hypothesis that would be tested. First, we found wind turbines that had similar outputs and sweep areas; however, Mitsubishi is following a smaller wing span limitation set by the nation of Japan (Mitsubishi had only for the outputs near 2500 on the website). From there we found their estimated outputs when placed at Vaughn, New Mexico; Miami, Florida; and found the original location's air density for the wind turbines. The medium for the program would be java. Java provided us with more of an object based approach then Starlogo and Netlogo for individual analysis of individual wind turbine designs. The key formula would be the wind power formula; an important segment was the sweep area of the wind turbine.

4.1 The Program

The program was originally to be made in Net logo, but we found that the project focused more on an object based manner then an agent based model. Java would allow us to gather information from the user and then calculate and display the information using numbers, an object, or a graph. Since one of our team members had prior experience with Java it became the best option. Java Scanner class was included to make the program ask for user input. This meant that the program did not need to be made for individual wind turbines but was universal. The program would ask the users for Sweep Area (double ax), Air Density (double dx), and Air Velocity (double vx), and Output (doubles p and mp), the three parts of the wind power formula and its result. The program would store the values in doubles (so decimals could be used for more reliable accuracy) then calculate the outputs while taking into consideration Bertz's Limit. Finally the program presents the estimated outputs in kilowatts. An if/else statement was added to check if any watts were predicted. If the value returns either zero or negative then the program displays: "No Energy Was Produced.". Since the program simply asks for inputs the program works with any wind turbine. Another use is that it can allow for predictions of wind turbine outputs while the wind turbine is being designed.

Fig.6 The Code

```
import java.util.Scanner;

@SuppressWarnings("empty-statement")

    public static void main(String[] args) {

        //Variables

   double vx; //wind speed

   double dx; // air density

   double ax; // sweep are

       //scanners and printed questions

       System.out.println("Welcome");

       System.out.println("Input wind speed");

       Scanner v = new Scanner(System.in);// wind speed(m/s)

       vx = v.nextDouble();

       System.out.println(vx+ " m/s");

       System.out.println("Input Density of the wind");

       Scanner d = new Scanner(System.in);// density(kg/m^3)

       dx = d.nextDouble();

       System.out.println(dx+" kg/m^3");

       System.out.println("Input Area of Effect");

       Scanner a = new Scanner(System.in);// swept area(m^2)

       ax = a.nextDouble();

       System.out.println(ax+" m^2");

       double p = (.5*dx*ax*(vx*vx*vx))/1000;
```

```
double mp= p*.53;
if (p <= 0) {
     System.out.println("No Energy Was Prodeced.");
 } else
    System.out.println(mp+" kilowatts");
  }
```

Fig.7 Example on how it works

-Welcome

-Input wind speed

-12 (input)

-12.0 m/s

-Input Density of the wind

-1.25 (input)

-1.25 kg/m^3

-Input Area of Effect

-8000 (Input)

-8000.0 m^2

-4579.2 kilowatts

5. Results

In order to compare the energy outputs of a wind turbine design at different locations, a series of different tables were constructed. The variables were listed and compared to each other in the tables. The tables are also organized by how much energy the wind turbine made in its original location and by its model. Not all the wind turbine models are included some categories because these models were not able to create that much electricity. Vaughn, New Mexico also seems to be the ideal place compared to all the other locations to put a wind turbine at because of the air speed.

With high output wind turbines had a substantial increase in radius then lower output wind turbines. This was proven by Vestas model v164-8.0MW which had an output of 8000kw. This, when compared to GE's 3.2-103 model, is an increase of 159.22% in wing radius; however, the output increased an astounding 266.67%. This provided the information needed for the testing of the hypothesis. The hypothesis was: Would larger wind turbines increase the viability of wind turbines in New Mexico? Larger wind turbines did make a substantial difference but had a limit: location. Places like Japan had a very limited space and cannot have wind turbines with higher outputs. New Mexico however, has large quantities of land. Wind turbines with larger radius are the most effective way to increase power with current technology available.

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Wind Turbines with outputs near 2500KW

	Wind Turbine Models (Vestas 100-2.6MW Model)				
	0.5	SA(m^2)	v ($^m/_s$)	ρ ($^{Kg}/_{m^3}$)	KW
Original location	0.5	7845	12.5	6.39597E-7	2600
Vaughn, New Mexico	0.5	7845	15.6464	0.986	7860. 623
Sea level	0.5	7845	8.49	1.265	1611.203

	Wind Turbine Models (GE 2.5-100 Model)				
	0.5	SA(m^2)	v ($^m/_s$)	ρ ($^{Kg}/_{m^3}$)	KW
Original location	0.5	7450.88	12.5	6.48274E-7	2500
Vaughn, New Mexico	0.5	7450.88	15.6464	0.986	6653.606
Sea level	0.5	7450.88	8.49	1.265	1528.506

	Wind Turbine Models (Vestas 100-2.6MW Model)				
	0.5	SA(m^2)	v ($^m/_s$)	ρ ($^{Kg}/_{m^3}$)	KW
Original location	0.5	7845	12.5	6.39597E-7	2600
Vaughn, New Mexico	0.5	7845	15.6464	0.986	7860. 623
Sea level	0.5	7845	8.49	1.265	1611.203

Wind Turbines with outputs near 2750KW

	Wind Turbine Models (GE 2.5-100 Model)				
	0.5	SA(m^2)	v (m/s)	ρ (Kg/m^3)	KW
Original location	0.5	11309.733	12.5	4.6979E-7	2750
Vaughn, New Mexico	0.5	11309.733	15.6464	0.986	11319.27
Sea level	0.5	11309.733	8.49	1.265	2582.783

	Wind Turbine Models (Mitsubishi MWT9 2.4MW Model)				
	0.5	SA(m^2)	v (m/s)	ρ (Kg/m^3)	KW
Original location	0.5	6448	12.5	6.975E-07	2400
Vaughn, New Mexico	0.5	6448	15.6464	0.986	6653.606
Sea level	0.5	6448	8.49	1.265	1363.799

Biggest of the three companies Wind Turbines Outputs

	Wind Turbine Models (Vestas 164-8.0 MW Model)				
	0.5	SA(m^2)	v (m/s)	ρ (Kg/m^3)	KW
Original location	0.5	21124	11.	1.07372E-7	8000
Vaughn, New Mexico	0.5	21124	15.6464	0.986	21141.81
Sea level	0.5	21124	8.49	1.265	4824.05

Wind Turbines with outputs near 3200KW

	Wind Turbine Models (Vestas 105-3.3MW Model)				
	0.5	SA(m^2)	v ($^m/_s$)	ρ ($^{Kg}/_{m^3}$)	KW
Original location	0.5	8659	12.5	7.36326E-7	3300
Vaughn, New Mexico	0.5	8659	15.6464	0.986	8666.302
Sea level	0.5	8659	8.49	1.265	1977.44

	Wind Turbine Models (GE 2.5-100 Model)				
	0.5	SA(m^2)	v ($^m/_s$)	ρ ($^{Kg}/_{m^3}$)	KW
Original location	0.5	8833.289	12.5	1.91299E-7	3300
Vaughn, New Mexico	0.5	8833.289	15.6464	0.986	8339.316
Sea level	0.5	8833.289	8.49	1.265	1902.83

6. Conclusion

There is no clear cut solution to improve all wind turbines. Wind overall is a very unreliable resource due to its inconsistency; however, with technological advances, wind turbines have allowed them to run on significantly lower wind speeds which are much more consistent. Another problem is that different places have different air conditions. This is why the outputs changed from location to location. Higher air density at the same speed will grant higher expected outputs.

7. Discussion

We all have dedicated a ton time to this project and have found it to be a rewarding experience. While we have learned the many challenges that go into creating a wind turbine, we have learned to have patience and preserve when times get hard.

Our first method did not work. Our first method was to create an actual wind turbine and test it at different locations in Los Lunas and then plug in that data into the program to determine the energy output of the wind turbine. We were also supposed to build different blade designs to see how the wind blades effects the energy output of the wind turbine; however, the more research we did on the internet the sooner we came to realize that no matter wind turbine we built that it could not compare to the ones of major companies. We should also mention our high school is going under construction including the wood shop room where we built all our wind blades. We were not able to access the wood shop anymore which meant we could not work on the blades anymore. We did not know what else to do for about two weeks until one team member came up with idea that we should use data from big time wind turbine companies to input into the program instead. The program failed many times. The program would often give us a negative energy output or would give us a high number for it. We had to patient and work on the program until we got it to work proficiently.

Next, we will be working on comparing off shore wind turbines and find which places of the Atlantic and Pacific Ocean, with in United States territory, are the locations to put a wind turbine to acquire maximum output. We will also include more variables into the program such as the materials used to create wind turbine blade and to see if whether it makes a difference on its performance.

We have been inspired to become Computer Scientists and Engineers in the future ever since participating in Super Computing Challenge. We have never considered going into the study of renewable energy before this, however, we were prompted with the idea of going into the renewable energy field after learning about how important it is to have in order to have a sustainable future. Finishing the program has given many opportunities to think about in environmental science. There are so many uses for computer programming in the field of environmental science that can help solve problems that matter to the well being of the future.

8. Acknowledgements

We would like to thank our Sponsor Ms. Loveless for helping us and never giving up us on this project.

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