Analysis of wind power generation with application of wind tunnel attachment

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ANALYSIS OF WIND POWER GENERATION WITH APPLICATION OF

WIND TUNNEL ATTACHMENT

An Abstract of a Dissertation

Submitted

in Partial Fulfillment

of the Requirements for the Degree

Doctor of Technology

Approved:

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Dr. Mohammed F. Fahmy, Committee Chair

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December 2013

ABSTRACT

This study presents an empirical method for developing a new approach in which a wind tunnel apparatus is used to improve the efficiency of power output by a small-scale wind turbine. A custom-designed wind tunnel attachment was constructed to record, analyze, and interpret both incoming and outgoing wind velocity readings. Moreover, the dissertation project addresses a significant issue concerning the power generation of an experimental wind turbine while the wind tunnel is attached.

Wind power characteristics that indicate power output versus wind velocity were obtained by performing a number of case studies. The case studies included normal operation of the experimental wind turbine at variable wind velocity values with and without the proposed wind tunnel.

The statistical t-Test and One-way ANOVA analyses were performed to suggest whether or not the proposed approach would be useful for wind turbine manufacturers to evaluate the degree that contributes to the variability of renewable energy production. Besides, the results may be helpful to support educational institutions in providing renewable energy awareness in Iowa and in the US by providing adequate information for the selection and handling of the parameters that control the variability of the energy needs.

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CHAPTER I

INTRODUCTION

Motivation and Background

Wind energy development is booming worldwide with China and the United States being forerunners in installed capacity. Wind power capacity additions are growing at a rapid pace in the United States. The U.S. wind industry now totals 51,630MW, according to the U.S. Department of Energy (DOE, 2013) and American Wind Energy Association (AWEA), and more than 40,000 turbines utilized through the end of September 2012 (AWEA, 2013). Because of the developing wind power investment, an efficient way of managing wind energy generation is needed. A custom-made wind tunnel attachment may increase the amount of energy produced by a wind turbine. This study will investigate whether a custom designed wind tunnel attachment is a suitable apparatus to increase the wind power output or not.

Statement of Problem

The problem of this study is to determine the appropriateness of attaching a custom-designed and constructed wind tunnel and managing wind power generation by an experimental small-scale wind turbine, in improving the power output harvested from such wind turbine.

Purpose of the Study

The main purpose of this study is:

1. To determine the physical specifications for the wind tunnel attachment apparatus and its components.
2. To predict the overall power output of a small-scale wind turbine on a monthly basis.
3. To develop educational models for integrating the system into the wind turbine industry.

Need and Justification

Because of high-energy costs today, many people are becoming more and more financially strapped, concerned about global warming and the effects of air pollution (Bollen, Hers & Zwaan, 2010). The United States has a vast supply of coal, with almost 30% of world reserves (Hook & Aleklett, 2009). The US is also the world's second largest coal producer after China and annually produces more than twice as much coal as India, the third largest producer (Hook & Aleklett, 2009). However, the reserves in the US concentrated in a few states, decreasing from 29.2 MJ/kg in 1950 to 23.6 MJ/kg in 2007 as U.S. production moved subbituminous western coals (Hook & Aleklett, 2009). In the generation of one kilowatt hour (kWh) of electricity by burning coal, 1kg of Carbon Dioxide (CO2), seven grams of sulfur oxides, nitrogen oxides and particulates, more than 200 grams of ash and waste amounts of several different metals are released (Hyslop, Davies, Wallace, Gazey & Holroyd, 1997) such as hydrogen sulfide (H_2S), hydrocarbons ethane (C_2H_6), Methane (CH_4), etc. (Stracher & Taylor, 2004). In 1996 CO_2 levels were around 345,000 parts per billion, (Klingenberg, 1996) contrasted to 290,000 parts per billion 100 years ago (Graedel & Crutzen, 1989). Wind energy systems reduce U.S. dependence on fossil fuels, and they do not emit greenhouse gasses (U.S. Department of Energy, 2013). The generation of electricity is not, of course, the only cause of record levels of CO_2 and other greenhouse gases in the atmosphere, but it does represent a large share (Graedel & Crutzen, 1989).

Hence, environmentally friendly wind power generation is proven to reduce the green house gas emissions in the atmosphere. In much of the United States, wind speeds are low in the summer when the sun shines brightest and longest. The wind is strong in the winter when there is less sunlight available (U.S. Department of Energy, 2013). Wind tunnel attachment's ability to capture low speed winds at lower altitudes may decrease the overall cost of the wind turbine and improve its efficiency. Renewable source of energy production could play a big role and wind power generation takes a large portion of such sources, especially when it comes to the state of Iowa.

Successful large wind – power projects using hundreds of very large wind turbines exist in several states. Being the second largest producer of wind energy in the nation, Iowa has several of these large-scale projects (Iowa Energy Center [IEC], 2013). Today, U.S. wind energy installations produce enough electricity on a typical day to power the equivalent of more than 9.7 million homes (U.S. Department of Energy, 2013).

The five-year average annual growth rate for the wind industry now is 39%, up from 32% between 2003 and 2008 (U.S. Department of Energy, 2013). All of such installations could benefit from the wind tunnels in securing wind power generation and management as well as prolonging the life and durability of wind turbines. This project intends to provide data, which make aids available in deciding on how big an impact of wind tunnel attachments to wind turbines can improve and secure continuous wind energy generation. The exact relationship between wind speed and extracted power is one that must be carefully evaluated for a particular site (IEC, 2013). Several authors of the wind energy textbooks and publications try to base the success of any wind generation system on generalized wind speed data charts collected from the National Weather Service (NWS) data. They also base their data on whether the site is on a hill, or in a valley, surrounded by trees, how close are the trees and how tall; what is the capacity of the rotor used, what is the efficiency of the rotor, at what wind speed does it operate etc. (National Renewable Energy [NREL], 2013). These are good places to start an investigation and for sure they need to be considered. Moreover the use of a wind tunnel attachment to a wind turbine could make the power generated more efficient and secure regardless of the aforementioned factors.

Hypothesis/Research Questions

The goal of this research was to develop and evaluate a wind tunnel attachment for Hampden Model H-WPG-1B-CA Wind Turbine in the natural environment and inside a controlled laboratory. The Hampden Model H-WPG-1B-CA selected for this study is a small – scale Wind Turbine with 400W power rating (Hampden, 2013).

Hypothesis 1: The null hypothesis, $H1_0$ is that there is no significant difference in the wind velocity means with the use of a custom-constructed wind guide attachments.

The alternate hypothesis, $H1_1$ is that there is a significant difference in the wind velocity means with the use of a custom-constructed wind guide attachments.

Hypothesis 2: The null hypothesis, $H2_0$ is that there is no significant difference in the wind power output with the use of a custom-constructed wind guide attachments and that such attachments will not affect the energy generation during low wind speeds.

The alternate hypothesis, $H2_1$ is that there is a significant difference in the wind power output means with the use of a custom-constructed wind guide attachments and that such attachments will affect the energy generation during low wind speeds.

Assumptions of the Study

For this study certain assumptions were made that would serve as the basis for ensuring analysis. These assumptions were:

1- The values of the power output of the wind turbine generated by the experimental wind turbine are relatively accurate.
2- The atmospheric pressure will be the same at each location.
3- Unexpected disturbances and uncontrollable influences have insignificant effect on the process and may be rounded or deleted from the analysis.

4- The power output specifications provided by the manufacturer is correctly developed and assumed to be a standard for all processes.

Objectives

The author proposed to build a custom - designed wind tunnel attachment for an experimental small-scale wind turbine as a possible tool to improve power output. In this experimental study he intended to achieve the following three goals:

1. Construct a custom designed wind tunnel attachment.
2. Conduct indoor and outdoor experiments and observe the effect of the wind tunnel attachment in various wind conditions.
3. Complete a statistical analysis and interpret whether the wind tunnel attachment meets the planned criteria.

CHAPTER II

REVIEW OF RELATED LITERATURE

Introduction

In the review of literature, there are a wide variety of research sources that have been carefully examined. The literature review consists of two major points: (a) impact of wind augmentation apparatus on wind speed, and (b) power output differences with the use of custom-constructed wind augmentation systems.

Renewable energy such as wind energy and solar energy are receiving great attention due to the price fluctuation of fossil fuels in the international market as well as the adverse environmental problems from the process of power generation from fossil fuels. Kim Bertelsen (2011), the owner of Electricon Inc. and a lightning protection expert, stated that wind turbines are constantly increasing in size and complexity. The wind turbines are relied upon as power plants in the overall power production planning. If a sudden small interruption occurs, the effects cannot be tolerated and the turbine is disconnected - leaving the grid on its own plants (Bertelsen, 2011). The modern wind turbine has to stay connected even during a thunderstorm - and this can no longer be claimed as an inevitable accident. It is decided that these machines should be running out there and this demands the same approach to lightning protection, as well as known from conventional onshore power plants (Bertelsen, 2011).

The US is expecting an increase in the number of re-powering projects in wind farms that were constructed 10-15 years ago, which consist of replacing old turbines with the new ones that may provide much higher power output. US, China and India are the new high growth markets. The development of the US market is dependent upon the successful implementation of President Obama's plan for renewable (Bertelsen, 2011). The member states of Europe have taken effort to increase the energy efficiency by 20% and reduce their global warming emissions by 20% by 2020 based on 1990 levels (Chong et al., 2013).

Wind Speed Augmentation

The energy (P) generated by a wind turbine is proportional to the swept area (A) of the turbine and the third power of the wind speed (v), as follows (Matsushima, Tahagi & Muroyama, 2006). Figure 1 shows the illustration of wind speed vs. power relationship for the experimental wind turbine.

$$P = \frac{1}{2}\rho A v^{3} \quad (\rho\text{: density of air})$$

Therefore, enlarging the swept area (A) or increasing the wind speed (v) can effectively increase the power output. In particular, since, the output is proportional to the third power of the wind speed, increased output will be obtained even with a slight increase in wind speed. One idea for increasing wind speed is the attachment of a wind augmentation apparatus to a wind turbine to be presented in this study.

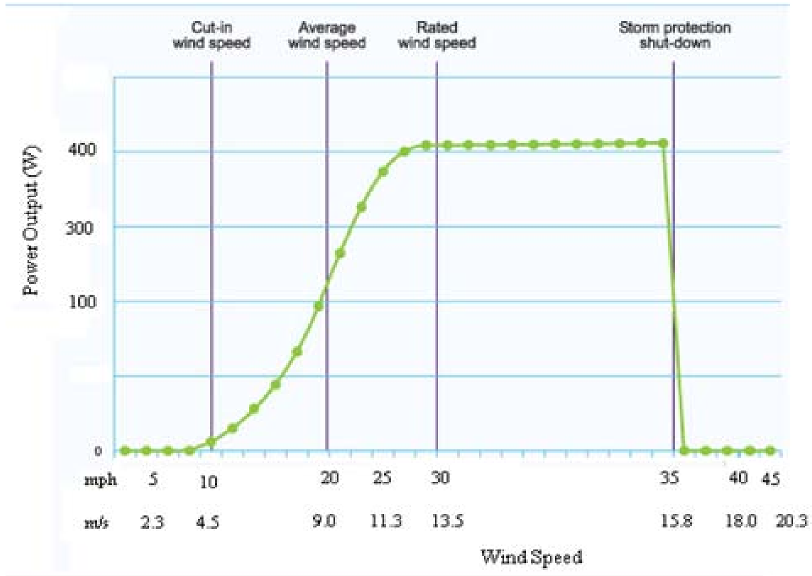


Figure 1. Power vs. Wind Speed characteristic of experimental Wind Turbine (Modified University of Northern Iowa, 2013)

An experimental research with a custom-constructed wind tunnel attachment was carried out by Ulan Dakeev (2011) showed that power generation of an experimental small-scale wind turbine increased by 60.02% and the start wind speed of the turbine dropped to 1.5 m/s from 5 m/s (Dakeev, 2011). Additionally, Tao, Zheng, Su and Riffat, (2011) conducted a solar-wind hybrid power generation, where a custom-constructed wind augmentation apparatus enabled the short circuit current to be increased by 10% averagely and the start wind speed to be reduced by about 1.5 times from 3 m/s to 2 m/s making about 66.6% improvement (Tao et al., 2011). Similar applied experimentation was conducted for a vertical axis wind turbine (VAWT) by Chong et al.(2013), which resulted in 75.16% rotor rotational speed increase and 5.8 times power output at 3 m/s wind speed (Chong et al., 2013). Proposed custom - designed wind tunnel apparatus was intended to contain a wind guiding attachment to prove that the custom constructed wind augmentation apparatus with wind guiding attachment may increase the power output of the experimental wind turbine.

CHAPTER III

METHODOLOGY

Overview of the Methodology

The project involves testing and analyzing a proposed model to verify the performance of an experimental wind turbine in indoor and outdoor environments. This includes the development of a custom constructed wind tunnel attachment. An anemometer and power-meter tool was used to conduct the experiment and collect data. In order to test the proposed project in real indoor and outdoor environments, three locations had been selected to complete the study. A statistical analysis package IBM SPSS was used for the analysis of collected data.

Description of the System

The system in this study consists of a wind turbine and the custom – constructed diffuser as a wind turbine attachment. A typical wind turbine consists of the rotor (three blades and hub), gearbox, conversion system, controls, and tower as shown in Figure 2. The author intended to construct a real examination device by fitting a diffuser to the experimental small-scale horizontal axis wind turbine and to examine the effects the system on output power generation, in both outside field test and in closed laboratory area. The results of the experiment and the obtained field test data were analyzed using SPSS® 21 software. A 45-inch industrial fan was used to generate artificial wind speed.

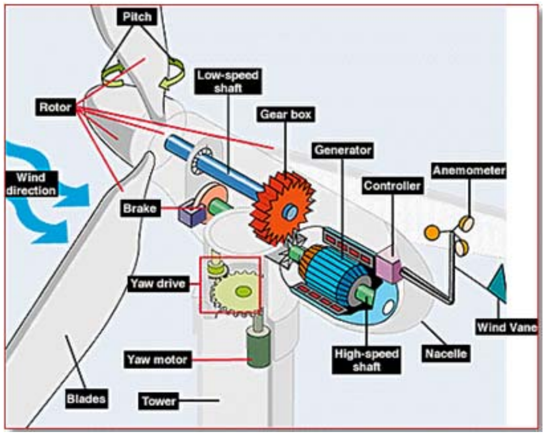


Figure 2. A typical wind turbine components (Modified National Renewable Energy Laboratory, 2013)

<u>Turbine Specifications for the Proposed Scheme</u>

The output data was obtained using a three-blade model shown below in Figure 3b. As with the original set, the turbine has a rotor diameter of 45 inches (114.3 cm) made of fiberglass reinforced plastic. In high wind speeds (greater than about 15.8 m/s (35 mph), the turbine will turn out of the wind (known as furling) to protect the turbine from over-speeding. The wind turbine was positioned in the open area where an average wind speed is 5 m/s (11.2 mph) at the time of the experiments. The tip gap was kept, as minimum as practically possible i.e. 5 in, and the turbine was placed in a wind tunnel attachment. Industrial fan was used to produce artificial wind, with minimum diameter of 42 inches. Variable wind velocity was measured with an anemometer (wind speed measuring device).

Experimental Location Selection

Two outdoor and one indoor location were selected to collect and evaluate the data to produce from the proposed design. The first experiment was carried out at the William S. White Building Parking lot (9) northwest of William S. White Building (8), Flint Michigan and at the Faculty/Staff Parking lot (24) northeast of Central Energy Plant (23), Flint, Michigan as seen in Figure 3. These outdoor locations were considered to be optimal with average 13mph wind speed (Null, 2011).

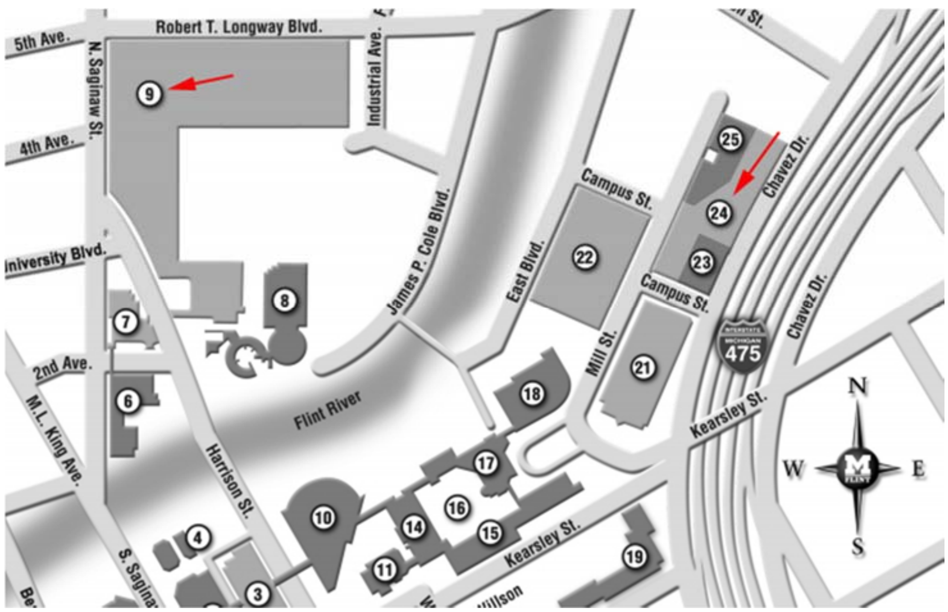


Figure 3. Outdoor Experimental locations (Modified University of Michigan – Flint, 2013)

EGR 115 laboratory of the University of Michigan – Flint Engineering Department (Figure 4) was used to conduct tests on a 400W The Hampden Model H-WPG-1B-CA experimental small – scale Wind Turbine. To run the experiment in real time measurements, the wind turbine was tested with the proposed wind tunnel apparatus attachment and a bare wind turbine in the MSB 115 Laboratory and other two selected outdoor sites, where human presence, trees, buildings or walls are minimal.

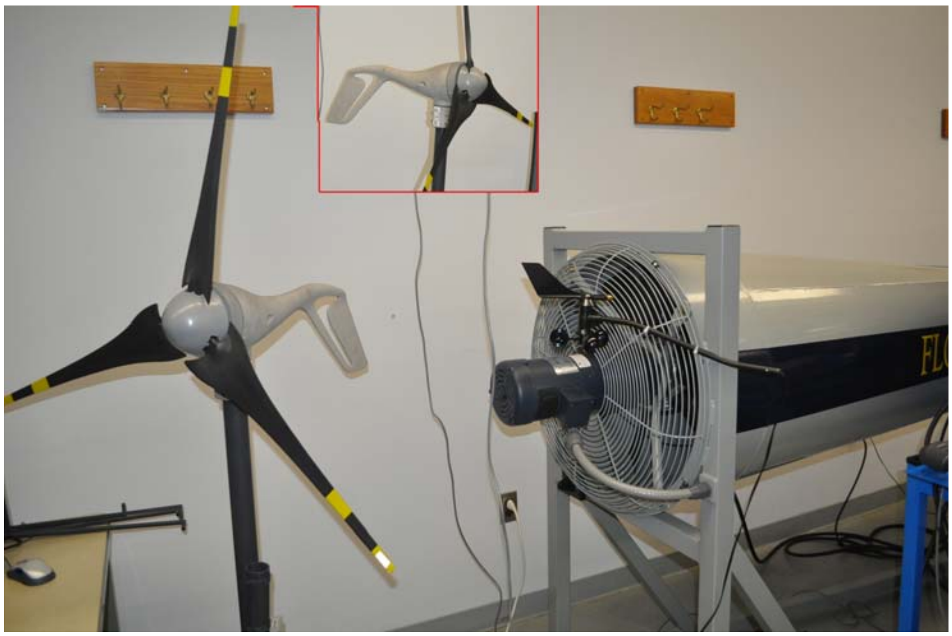


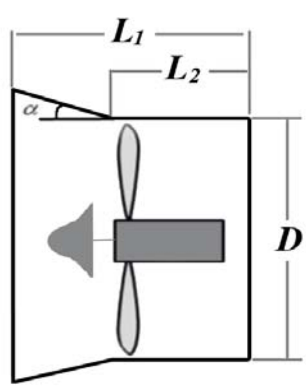
Figure 4. MSB 115, Engineering Department, University of Michigan-Flint

Development of Wind Tunnel Attachment

An engineer-technician of the University of Michigan (further UofM) - Flint was communicated to complete the construction of the wind tunnel apparatus out of sheet metal. Additionally, an undergraduate student from Mechanical Engineering Department Toufiq Hussain assisted in developing the custom constructed wind tunnel attachment. The reason in involving the undergraduate student in this study was to develop experimental research skills of the student. The Undergraduate Research Opportunity Program (UROP) of UofM-Flint (2013) states:

> "*The Undergraduate Research Opportunity Program (UROP) is designed to support collaborations between UM-Flint undergraduate students and faculty researchers. UROP allows students to earn paid (or volunteer), hands-on research experiences working along faculty on cutting-edge projects. Additionally, faculty are afforded the opportunity to mentor enthusiastic and talented students.*"

The undergraduate research proposal for UROP required training in appropriate research conduct practices for both faculty and the student involved in the project. The approved UROP documentation can be found in the Appendix C. Construction of the wind tunnel apparatus required meeting the specifications of the experimental Hampden Model H-WPG-1B-CA Wind Turbine. The wind tunnel apparatus (WTA) test section diameter must exceed 42" in order to accommodate the wind swept area of the wind turbine as shown on Figure 5. A preliminary set of dimensions was proposed to the engineer technician of UofM - Flint. In case of necessity to adjust the proposed specifications, technician's final dimensions were to be used to reflect the change.



L1=100-115cm

L2=70-75cm

D=50"

α=30^0

Figure 5. Schematic cross sectional view of a wind turbine and WTA

Construction of the System

In order to meet the specified requirements for the wind tunnel attachment system a three (3) millimeter thick sheet metal was rolled to obtain 50” diameter tunnel as illustrated in Figures 6a and 6b below. Two 96” X 78” sheet metals were resized to 157.08 circumference for connection with rivets to minimize the possibility of friction and turbulence generation while the air moved inside the wind tunnel apparatus.

Figure 6a. 96”X78”, 3mm sheet metal

Figure 6b. 50” diameter WTA

The experimental rig was designed with detachable wind guide attachment. The wind guide attachment was placed at the center of the wind tunnel apparatus to force incoming airflow from inlet section towards the tips of the experimental wind turbine. Two cone and bell shaped wind guide attachments were constructed out of the same 3mm thick sheet metal to provide smooth movement for the incoming air. The cone shaped wind guide attachment was tested first to allow comparison of bare turbine with the proposed system as illustrated in Figure 7 below. The construction of the system carried out inside the EGR 167 metal-wood workshop of the University of Michigan – Flint. Toufiq (research assistant) utilized two (2) rods 3/4" to stabilize the wind guide apparatus at the center of the tunnel (Figures 8, 9, 10). The rods were placed at the back of the wind guide attachments to eliminate possible drag generation from the flowing air. Wind speed was simulated hitting the front face of the WTA, passing through the diffuser's main body length (L), and hitting the rotor at WTA inner diameter (D).

Figure 7. Cone shaped wind guide attachment

Figure 8. Research assistant with WTA

Figure 9. Stabilization of the Wind Guide Attachment

Figure 10. Stabilization of Wind Guide Attachment

Data Collection and Analysis

Pretest and Post-test experiments were conducted for the experimental wind turbine with and without the use of wind tunnel attachment. Recorded wind speed data obtained from Iowa Energy Center (2013) simulated to conduct the experiments in EGR 115 Laboratory. Total of sixty two (62) for the bare wind turbine, and hundred and twenty four (124) wind speed data was recorded for the wind tunnel augmentation system. Sixty two (62) wind speed data was collected for the cone shaped wing guide attachment. Additional sixty two (62) wind speed data was recorded for the bell shaped wind guide attachment. Collected data was recorded and analyzed in MS Excel 2013 and IBM's SPSS version 20 software for comparison reasons. As a final phase the analyzed data was interpreted for the concluding results.

Limitations/Delimitations

The limitations for the development of this study were as follows:

1. The study would be conducted only using the experimental Hampden Model H-WPG-1B-CA Wind Turbine manufactured by Hampden Company.

2. The testing would be conducted at variable indoor wind conditions.

3. The fan used in the system as wind source may have a diameter of 30” or larger with maximum wind speed generation of 15 m/s.

The Experiment

In order to perform the data analysis related to the wind turbine experiments properly, a number of sixty two (62) tests were performed with an artificial wind generated by 45” industrial fan illustrated in Figure 11 below at 5.88 m/s (13.16 mph) wind in average. Note that the size of the wind tunnel attachment was limited by the size of the experimental wind turbine and 50” diameter was chosen to accommodate the wind turbine. The augmentation effect of the wind tunnel apparatus and the wind guide attachments was significant compared to the bare wind turbine.

The starting wind speed for the wind turbine was 2.2 m/s (5 mph); the average wind speed collected during the experiment 5.88 m/s (13.16 mph) produced average 279.65 watts of power on the wind turbine. The maximum wind speed needed to generate the optimum power from the 400W wind turbine was 4.73 m/s.

Figure 11. 45” Industrial Fan

The final stage of the experiment took place in the 157 Laboratory of Engineering Department UM-Flint. The experimental wind turbine was placed inside the constructed wind tunnel attachment. A 45” diameter fan was placed in front of the intake contraction area of the wind tunnel to generate wind speed that hit the wind guide apparatus as shown in Figures 12 and 13. The role of the wind guide attachment (WGA) was to lead the airflow towards the tips of the wind turbine blades. Anemometer recorded that the wind speed generated at the center of the experimental wind turbine was 0.6 m/s (Figure 14). Minimum of 2.2 m/s cut in speed was required for the 400W Hampden wind turbine. This velocity was negligible due to the fact that the rotational speed of the wind turbine at the moment of 0.6 m/s was zero (0) revolutions per minute. Wind speed generation of the fan was controlled by the experimenter to produce various amount of wind velocity values that had been initially measured in the previous experiments without the wind tunnel attachment. The fan was placed 5” away from the intake of the wind tunnel. This enabled windflaw to hit the WGA area equally making smooth path towards the wind turbine blade tips. Wind data collection at Faculty parking lot and White Building parking lot resulted at 2.7 m/s in average. Wind data was downloaded from Iowa Energy Center and artificial wind was generated by the experimental fan to simulate the wind flow. The whole wind speed data can be observed in the Appendix A.

Figure 12. Alignment of the system

Figure 13. Wind Guide Apparatus

Figure 14. Wind Velocity at Wind Turbine Hub

Figure 15a. Wind Velocity at Faculty Parking Lot

Figure 15b. Wind Velocity at White Building

Statistical Analysis

The overall data analysis was completed using IBM's statistical package SPSS version 20. SPSS was developed by IBM, Inc and provides a selection of data analysis, data management, data mining, and data visualization procedures. Some of the features of the SPSS software include basic and multivariate statistical analysis, quality control modules and neural networks. Use of this statistical software helped in selecting a number of combinations of variables that can be statistically examined and graphed to assist in data interpretation and presentation.

CHAPTER IV

ANALYSIS OF THE RESULTS

Experimental Data

The controllable variables during the final stage of the experimental process were the wind speed and the wind guide apparatus mounted inside the wind tunnel attachment. In view of that, the data collected during the power generation experiments was classified in two main categories. The first category involved experimental wind turbine power output collection performed at different wind speeds with cone shaped WGA attached. The second category involved experimental wind turbine power output data collection performed at the same wind speed ranges artificially generated by the industrial fan with the with bell shaped WGA attached. National Weather Service (2013) indicated the atmospheric pressure for October 21st was 29.8 in (See Appendix B). The average wind speed for two thirds of October was 15 mph for Flint area (Figure16). During the data collection period, October 17th to October 21st the air pressure was observed stable at average 28 in as illustrated in Figure 16. The custom constructed wind tunnel attachment amplified input wind speed from 1.16 mph – 24.94 mph to 1.88 mph – 41.90 mph producing average from 279.65 Watts to 327.92 Watts. The reason that the upper range of the power generation is limited to 400 Watts is due to the maximum power generation capacity of the experimental wind turbine.

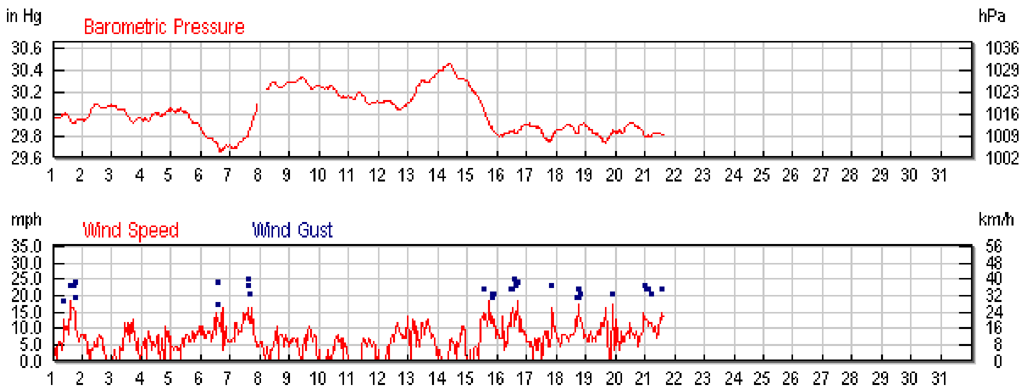


Figure 16. Wind Velocity and Air pressure

Data Analysis

This chapter is to provide a meaningful presentation and interpretation of the data set collected during the power generation experiments performed in this study. Three sets of data, sixty two (62) each, were collected for bare wind turbine and two different cases on the wind tunnel attachment with cone shaped apparatus and bell shaped apparatus mounted respectively making one hundred and eighty six (186) samples for the wind turbine power output. The relevant data analyses are presented both in table and figure forms with brief descriptions in this chapter and in Appendix A. All data analyses were completed using the statistical software SPSS version 20 from IBM, Inc and MS Excel 2013. For consistency reasons t-Test analysis was performed to determine and present a summary of the basic features of the collected data set. Tables 1 and 2 show the wind velocity and power output descriptive statistic results for both bell and cone shaped wind guide attachments on the WTA.

Descriptive Statistics

MS Excel 2013 descriptive statistic results obtained from wind velocity data with the cone shaped WGA, bell shaped WGA and bare wind turbine, Table 1 shows the effect of the cone shaped and bell shaped wind guide attachments on the wind velocity change from the experiment. Table 2 also presents the SPSS version 20 descriptive statistic results collected from wind velocity experiments with the use of both wind guide attachments and the bare wind turbine with no WTA involved.

Table 1. *MS Excel 2013 Wind Velocity Descriptive Statistics*

Bare Wind Turbine		*Cone Shaped WGA*		*Bell Shaped WGA*	
Mean	13.16	Mean	20.44	Mean	20.79
Standard Error	0.93	Standard Error	1.46	Standard Error	1.49
Median	11.79	Median	18.57	Median	18.56
Standard Deviation	7.32	Standard Deviation	11.52	Standard Deviation	11.77
Minimum	1.16	Minimum	1.73	Minimum	1.88
Maximum	24.94	Maximum	41.90	Maximum	41.90
Count	62	Count	62	Count	62

Table 2. *SPSS 20 Wind Velocity Descriptive Statistics*

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
BareWT	62	1.16	24.94	13.1586	7.31847
ConeWGA	62	1.73	41.90	20.4394	11.51834
BellWGA	62	1.88	41.90	20.7933	11.76518

Descriptive statistics obtained from both software present total number of 186 collected data. Mean wind velocity for the bare wind turbine, with no wind tunnel was attached. was approximately 13.16 mph with standard deviation 7.13. Significant increase in mean value is observed when cone and bell shaped wind guide attachments were involved in the system (20.43 & 20.79). Slight difference between bell and cone shaped mean shows that the shape of the wind guide did not have significant effect on the wind speed increase.

Figure from 17 through 19 show changes in wind velocity and power output over time. Wind velocity was increased with the use of wind tunnel attachment device with wind guides. However the difference between the wind speeds related to the shape of the wind guide attachment was hardly noticeable. This means the wind velocity was higher when using any of the wind guide attachments compared to the conventional wind turbine with no attachments. Until 2.84 m/s wind speed the energy production of the experimental wind turbine with WGA attachments was generally larger or equal to the bare wind turbine (Figure 19).

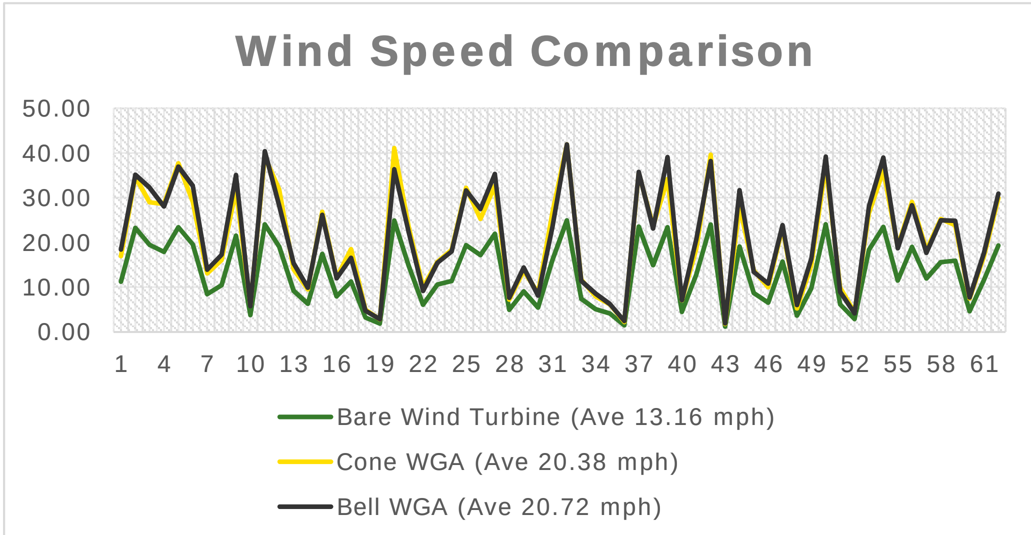


Figure 17. Wind Speed comparison over time (Run Chart)

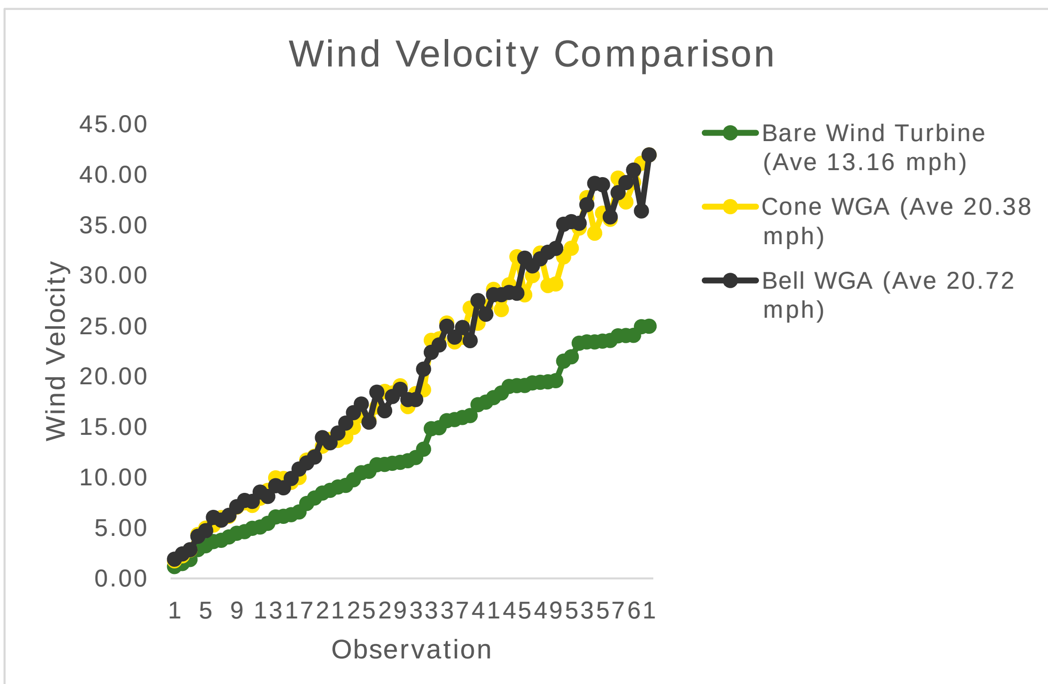


Figure 18. Wind Speed comparison over time

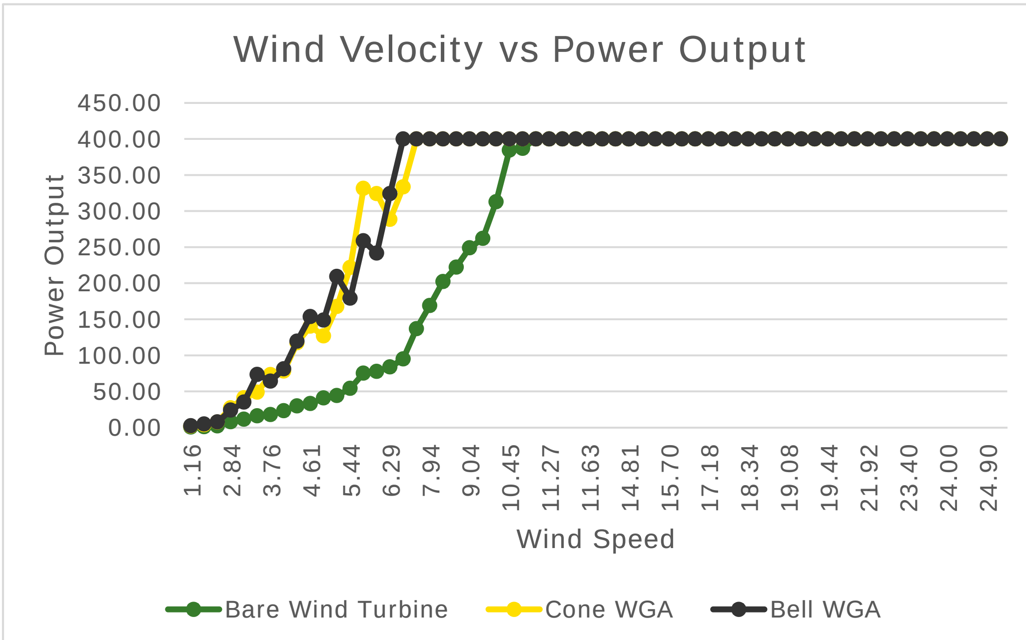


Figure 19. Wind Turbine Power Output

However, the proportion of energy that was generated by the test device increased to a maximum of 4.12 times at 6.55 m/s. Total energy production of the experimental wind turbine with wind guides attached during the test was 1.58 times the power output without the WGAs. A larger energy production that this, however, was expected given that the experimental wind turbine was capable of generating larger power output.

The histograms generated in SPSS ver. 20 shown in Figures 20 through 22 present the normality of the collected wind speed data during the experiments.

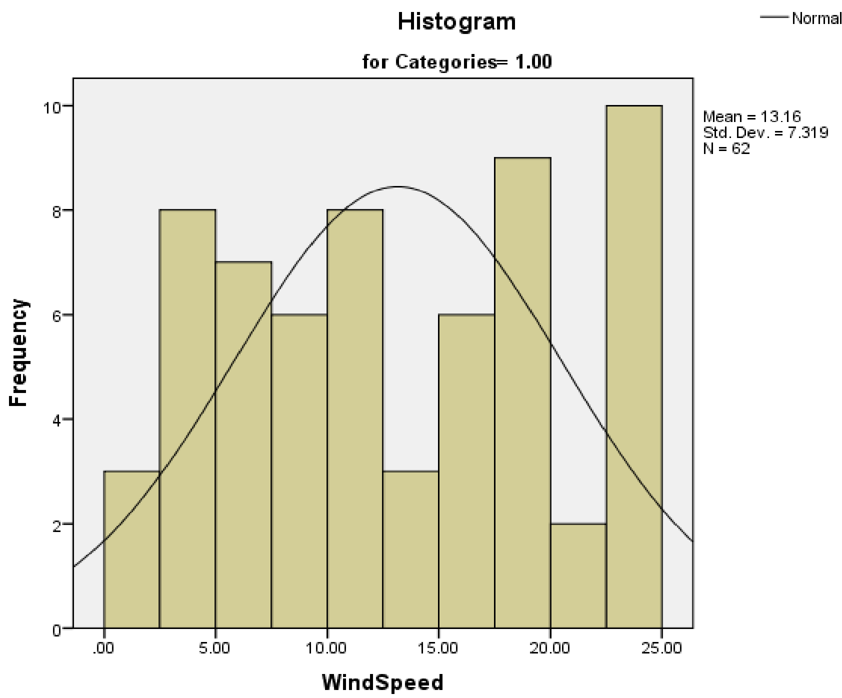


Figure 20. Wind Data Normality Plot for Bare WT

Factor 1 (Bare Wind Turbine) Kolmogorov – Smirnov test states that the analyzed data follows normal distribution if the calculated p-value is greater than .20 ($p>.20$) as seen in Table 3. Additionally, wind data for the WGA experiments shows normal as well.

Table 3. *SPSS 20 Normality Test*

Tests of Normality

	Categories	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
WindSpeed	1.00	.094	62	.200*	.938	62	.004
	2.00	.093	62	.200*	.954	62	.021
	3.00	.086	62	.200*	.948	62	.010

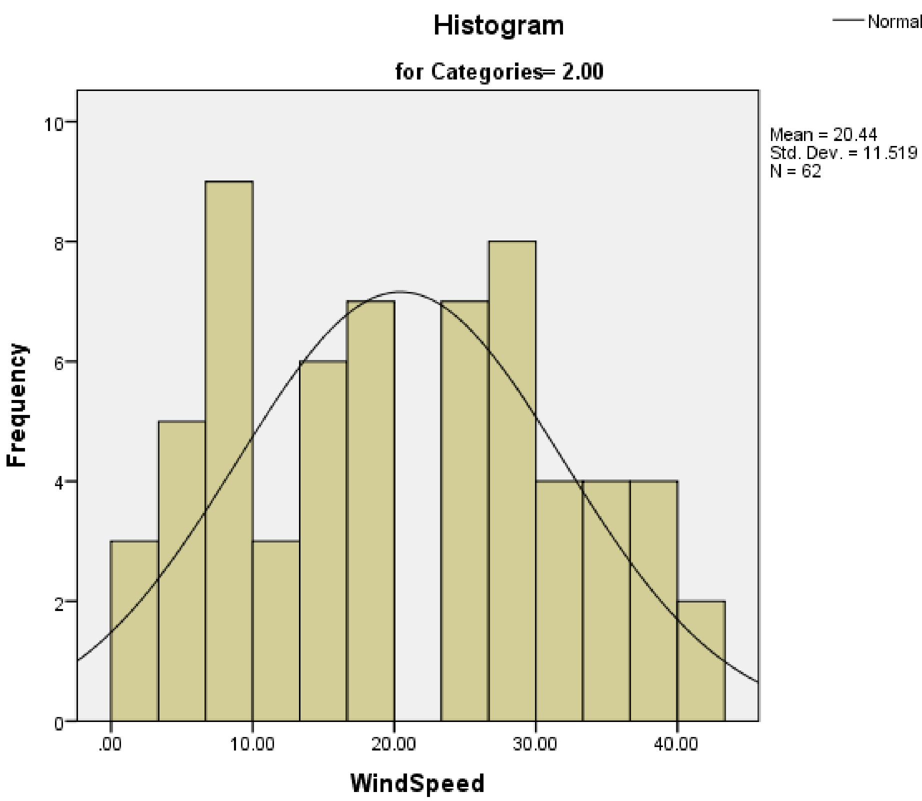


Figure 21. Wind Data Normality Plot for Cone WGA

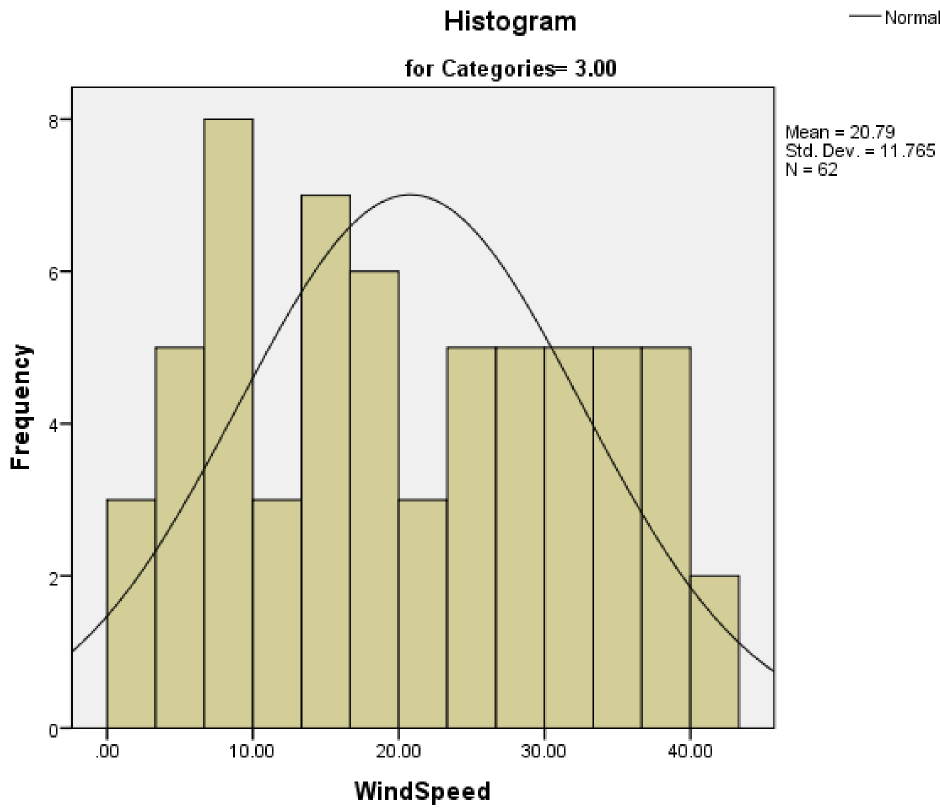


Figure 22. Wind Data Normality Plot for Bell WGA

T-Test Analysis

A t-Test analysis was performed on the difference of the wind velocity change in relation to the incoming wind speed influenced by the wind guide attachments to support the hypothesis that there is a significant difference between the average means of wind velocities when the wind tunnel attachment was used. A summary of a one-sample t-Test analysis at a 95% Confidence Interval (CI) with alpha level α=0.05 with the sample number N=62 for two tail are shown in Tables 4 and 5. The t-Test yields the mean of the

Category 2 (wind velocity on the cone shaped wind guide attachment) approximately as Mean=20.44 mph while the mean of Category 3 (wind velocity on the bell shaped WGA) resulted in approximately Mean 2=20.79 mph. The p-value obtained from the analysis was p=0.866 higher than the alpha level of 0.05, which indicates that there is no significant difference between the average means of the wind velocities with the use of different shapes of wind guide attachments. Additionally, t-Test analysis performed to compare power outputs with the bare wind turbine (no WGA attached) and cone shaped WGA attachment (Table 7) shows that there is no significant difference in power outputs by the experimental wind turbine.

Table 4. *Wind Velocity Group Statistics*

Group Statistics

	Categories	N	Mean	Std. Deviation	Std. Error Mean
WindSpeed	2.00	62	20.4395	11.51858	1.46286
	3.00	62	20.7929	11.76522	1.49418

Table 5. *Independent Sample t-Test Wind Velocity*

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	t	df	Sig. (2-tailed)	95% Confidence Interval of the Difference	
							Lower	Upper
Wind Speed	Equal variances assumed	.029	.865	-.169	122	.866	-4.49286	3.78608
	Equal variances not assumed			-.169	121.945	.866	-4.49288	3.78610

In the Group Statistics box (Table 6), the mean for Category 1 (No WGA attached) is approximately 279.65 Watts with 162.578 standard deviation for 62 values. The mean for Category 2 (Cone Shaped WGA) is approximately 327.94 Watts, which is 1.17 times higher compared to the power output without the wind guide attachment.

Table 6. *Group Statistics Power Output*

Group Statistics

	Category	N	Mean	Std. Deviation	Std. Error Mean
Power Output	No WGA attached	62	279.6476	162.57830	20.64746
	Cone Shaped WGA	62	327.9377	133.33951	16.93413

The two tailed independent t-Test analysis value (0.073) in Table 7 is higher than 0.05 alpha level, indicating that there is no significant difference in the power outputs when the cone shaped wind guide attachment was used. This is due to the capacity limitation of the experimental wind turbine that has maximum of 400 Watt power output rating. Since the power generated by a wind turbine follows the formula where power is equal to half of the air density multiplied the blade swept are and wind velocity cubed, it is logical to further investigate whether or not the wind guide attachments have any effect on the wind velocity.

Table 7. *Independent Sample t-Test Power Output*

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	t	df	Sig. (2-tailed)	95% Confidence Interval of the Difference	
							Lower	Upper
Power Output	Equal variances assumed	10.444	.002	-1.808	122	.073	-101.15262	4.57230
	Equal variances not assumed			-1.808	117.500	.073	-101.17291	4.59259

Analysis of Variance (ANOVA)

One-way analysis of variance was conducted to examine the effect of the wind guide attachments on differences in wind velocity changes of three sample groups for statistical significance. Additionally, one way ANOVA was conducted to examine the effect of the wind guide attachments on the mean power outputs. The independent t-Test analysis resulted that there is no significant difference in the wind velocity change when cone shaped wind guide attachment was introduced to compare with bell shaped WGA. Additionally, independent t-Test showed that there is no significant difference in power output means generated from the experimental wind turbine when cone shaped WGA was compared to the bare wind turbine with no WGA attached. The dependent variable, wind speed output, was normally distributed for the groups formed by the WTA. There was homogeneity of variance between groups assessed by Tukey's test for equality of error variances. Table 8 shows the one way ANOVA test results for the wind velocity output without wind guide attachment system referred as "No WGA," wind velocity output with cone shaped WGA referred as "Cone WGA," and the wind speed output with bell shaped WGA indicated as "Bell WGA."

Table 8. *One way ANOVA Wind Velocity Desciptives*

Descriptives

WindSpeed

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
No WGA	62	13.1582	7.31870	.92948	11.2996	15.0168	1.16	24.94
Cone WGA	62	20.4395	11.51858	1.46286	17.5143	23.3647	1.73	41.90
Bell WGA	62	20.7929	11.76522	1.49418	17.8051	23.7807	1.88	41.90
Total	186	18.1302	10.93154	.80154	16.5489	19.7115	1.16	41.90

Table 9. *One way ANOVA Wind Velocity*

ANOVA

WindSpeed

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2302.894	2	1151.447	10.640	.000
Within Groups	19804.357	183	108.221		
Total	22107.251	185			

One way ANOVA table above for N=62 in each category (Table 9) shows that there is significant difference between the wind velocity changes when custom constructed wind guide attachments are introduced. There was significant interaction between the wind guide attachments and the wind velocity output. Simple main effects analysis showed that the wind speed significantly increases with the use of wind guide attachments. A summary of one way ANOVA at 95% Confidence Interval (CI) with alpha level $\alpha=0.05$ and sample size N=62 is shown on Table 9. The test yields mean for bare wind turbine (No WGA) approximately $M1=13.16$ while the means for custom constructed attachments (Cone WGA and Bell WGA) resulted in approximately $M2=20.44$ and $M3=20.79$ respectively (Table 8). The p-value obtained from the analysis was $p= 0.000043$ lower than the alpha level $\alpha=0.05$, which indicates that there is a significant difference in wind velocity changes with the use of wind guide attachments.

Therefore null hypothesis $H1_0$ is rejected, where there is no significant difference in the wind velocity means with the use of a custom-constructed wind tunnel attachments.

Tukey's HSD test on Table 10 below shows that there is significant difference between the cone-shaped WGA (Category 2) and the bare wind turbine (Category 1). Moreover, the table shows that there is significant difference between the bell-shaped WGA (Category 3) and the bare wind turbine. Tukey's HSD also shows that cone shaped WGA resulted in highest wind velocity change followed by bell shaped WGA with a slight difference. Both WGA systems significantly amplify wind velocity from the bare wind turbine.

Table 10. *Tukey's HSD Post Hoc Test*

Multiple Comparisons

Dependent Variable: WindSpeed
Tukey HSD

(I) Categories	(J) Categories	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	-7.28129*	1.86842	.000	-11.6963	-2.8663
	3.00	-7.63468*	1.86842	.000	-12.0496	-3.2197
2.00	1.00	7.28129*	1.86842	.000	2.8663	11.6963
	3.00	-.35339	1.86842	.980	-4.7683	4.0616
3.00	1.00	7.63468*	1.86842	.000	3.2197	12.0496
	2.00	.35339	1.86842	.980	-4.0616	4.7683

*. The mean difference is significant at the 0.05 level.

One way ANOVA showed a significant effect of wind guide attachments in comparing wind velocity values. Additional one way ANOVA was performed to see WGA effects on the power output by the experimental wind turbine with maximum of

400 Watt power rating. Table 11 below is presented to illustrate the significance level of power outputs. The table shows that there is no statistically significant difference between three groups. Therefore we fail to reject null hypothesis $H2_0$ where there is no difference power output means when custom constructed wind guide apparatus were attached.

Table 11. *One way ANOVA Power Output*

PowerOutput

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	96229.992	2	48114.996	2.331	.100
Within Groups	3776645.100	183	20637.405		
Total	3872875.092	185			

Cost Effectiveness

Calculation of cost effectiveness of the proposed system included retrieving velocity data from wind map for Iowa for three (3) months September, October, and November 2013. All of the wind maps for these four months were retrieved from Iowa Energy Center web site and can be seen in the Appendix B. In the months of September, October and November 2013 the average wind speed for Iowa is basically calculated by taking the average of all wind speed averages retrieved from Iowa Energy Center (IEC) as seen in Table 13, Appendix A. Table 12 below shows the average wind velocities by months and equivalent power output by the experimental wind turbine. The power output vs. wind velocity for bare wind turbine and custom constructed wind guide attachments were retrieved from the experimental setups. Retrieved wind velocity data from IEC was simulated by the experimental industrial fan to obtain power outputs (see Appendix A).

Table 12. *Monthly Wind Velocity vs. Power Output*

Months	September	October	November	Overall Average
Wind Speed Averages (mph)	5.81	6.38	7.73	6.64
Wind Speed Averages Cone	9.94	9.49	12.07	10.50
Wind Speed Averages Bell	9.15	9.87	11.99	10.30
Power Output Bare WT (watts)	75.12	83.74	168.86	109.24
Power Cone Shaped WGA (watts)	331.34	288.32	400.00	339.89
Power Bell Shaped WGA (watts)	258.62	324.08	400.00	327.57

As it can be observed in the Table 12, the average wind speed in Iowa for the month of September was 5.81 mph and the experimental wind turbine with the capacity of 400W is capable of producing 75.12 Watts. By attaching wind guide apparatus to the same wind turbine, the wind speed increased from 5.81 mph to 9.94 mph and 9.15 mph for cone shaped WGA and bell shaped WGA respectively for the month of September. The average wind velocity for all three months increased from 6.64 mph to 10.5 mph also increasing wind power generation from 109.24 Watts to 339.89 Watts. Average household in the U.S. spends 940 kWh monthly (U.S. Energy Information Administration, 2013). Total installed wind energy at the end of 2012 was 5,137 MW in

Iowa (Department of Energy, 2013). The electric rate posted on the Cedar Falls Utility (CFU) website for 2013 is illustrated on Table 13 below:

Table 13. *Electricity rate from Cedar Falls Utility (Modified from CFU, 2013)*

MONTH	RATE
January 1, 2013	0.011
February 1, 2013	0.013
March 1, 2013	0.010
April 1, 2013	0.013
May 1, 2013	0.014
June 1, 2013	0.019
July 1, 2013	0.023
August 1, 2013	0.021
September 1, 2013	0.016
October 1, 2013	0.014
November 1, 2013	0.017
December 1, 2013	0.017

Electricity rate for the months of September, October and November 2013 are 0.016, 0.014, and 0.017 dollars per kWh. Based on this information an average house hold pays 940*0.016=15.04 dollars for the electricity. Total number of 5,464 households used 5,137 MW of wind energy installed in Iowa. Application of cone shaped wind guide attachment increased power generation by 22.6% in the month of September. Considering the WGA attachment was utilized on the currently installed wind energy in Iowa, total number of households using renewable wind energy would increase from approximately 5,464 to approximately 6,699. Total revenue generated from currently installed wind energy in Iowa is 5,137*0.016 = $82,192 with September CFU rate.

Produced wind energy with the application of WGA can increase the revenue by $100,767.39-82,192=$18,575.39.

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

Conclusion

The problems of this applied research study was to determine the strength of the relationship between power output and the custom-constructed wind tunnel apparatus with wind guide attachment. The null hypothesis, $H1_0$ was that there is no significant difference in the wind velocity means with the use of a custom-constructed wind guide attachment. Based on the statistical analysis (ANOVA) null hypothesis is rejected, where one way ANOVA showed that there is significant difference in wind velocity means with the application of custom constructed wind tunnel attachment. The power of a wind turbine could be increased or decreased by simply attaching a wind tunnel to it (Dakeev, 2011). Application of wind guide attachments can increase power generation by 22.6%. A general rule of thumb is to install a wind turbine on a tower with the bottom of the rotor blades at least 9 meters (30 feet) above any obstacle that is within 90 meters (300 feet) of the tower (U.S. Department of Energy, 2013). Wind tunnel attachment's ability to capture low speed winds at lower altitudes may decrease the overall cost of the wind turbine. Based on the experiment with statistical analysis, attachment of the wind guide attachment on the wind turbine may increase the power generation significantly at $\alpha = 0.05$ levels.

Recommendations

Further studies need to be considered on the Computational Fluid Dynamics (CFD) analysis on the design of the wind tunnel apparatus and the wind guide attachments. Custom constructed system can be modeled in the ANSYS Design Modeler, Meshed with optimal number of hexes and analyzed with ANSYS Fluent. The simulated air flow in the Fluent software may represent the effectiveness and/or validity of the constructed attachments. The cost effectiveness of the current system was not analyzed for large scale wind turbines therefore; transportation of the wind tunnel to far-distance areas might be costly.

REFERENCES

American Wind Energy Association, (2013). Retrieved from www.awea.org

Bertelsen, K., (2011). The update of IEC 61400-24 Lightning Protection of Wind Turbines. *29th International Conference on Lighting Protection.* [Electronic version]. Retrieved from www.germanlloyd.org

Bollen, J., Hers, S. & Zwaan, B., (2010). An integrated assessment of climate change, air pollution, and energy security policy. *Energy Policy*. [Electronic version]. Retrieved from www.elsevier.com

Cedar Falls Utility, (2013). Retrieved from www.cfu.net

Chong, W.T., Pan, K.C., Poh, S.C., Fazilzan, A., Oon, C.S., Badarudin, A.& Nik-Ghazali, N. (2013). Performance investigation of a power augmented vertical axis wind turbine for urban high-rise application. *Renewable Energy*. [Electronic version]. Retrieved from www.elsevier.com

Dakeev, U. (2011). Management of Wind Power Generation with the Attachment of Wind Tunnel. *Wind Tunnels-Design and Construction.* [Electronic version]. Retrieved from www.library.uni.edu

Graedel, T. & Crutzen, P. (1989). Policy options for stabilizing Global Climate. *National Service Center for Environmental Publications*. [Electronic version]. Retrieved form http://nepis.epa.gov

Hampden Engineering Corporation, (2013). Retrieved from www.hampden.com

Hook, M. & Aleklett, K., (2009). Historical trends in American coal production and a possible future outlook. *International Journal of Coal Geology.* [Electronic version]. Retrieved from www.elsevier.com

Hyslop, B., Davies, M., Wallace, A., Gazey, N. & Holroyd S. (1997). Effects of colliery waste on littoral communities in north – east England. *Environmental Pollution.* [Electronic version]. Retrieved from www.sciencedirect.com

Iowa Energy Center, (2013). Retrieved from www.iowaenergycenter.org

Klingenberg, C.P. (1996). Static, ontogenetic, and evolutionary algometry: a multivariate comparison in nine species of water spiders. *American Naturalist.* [Electronic version]. Retrieved from http://www.jstor.org

Matsushima, T., Takagi, S. & Muroyama, S., (2006). Characteristics of a highly efficient propeller type small wind turbine with a diffuser. *Renewable Energy.* [Electronic version]. Retrieved from www.elsevier.com

National Renewable Energy Laboratory (2013). Retrieved from www.nrel.gov

National Weather Service, (2013). Retrieved from www.weather.gov

Null, J., (2011). *Comparative Climatic Data, United States*. Retrieved from www.ggweather.com

Stracher, G. & Taylor, T. (2004). Coal fires burning out of control around the world: thermodynamic recipe for environmental catastrophe. *International Journal of* Coal Geology. [Electronic version]. Retrieved from www.elsevier.com

Tao, T., Zheng, H., Su, Y. & Riffat, S. (2011). A novel combined solar concentration/wind augmentation system: Constructions and preliminary testing of a prototype. *Applied Thermal Engineering.* [Electronic version]. Retrieved from www.elsevier.com

University of Michigan-Flint, (2013). Retrieved from www.umflint.edu

University of Northern Iowa, (2013). Retrieved from www.library.uni.edu

U.S. Department of Energy, (2013). Retrieved from www.energy.gov

U.S. Energy Information Administration, (2013). Retrieved from www.eia.gov

The Weather Channel, (2013). Retrieved from www.weather.com

APPENDIX A

DATA TABLES

Table 14. *Collected Wind Data during Experiments*

	Bare Wind Turbine	Cone WGA	Bell WGA		Bare Wind Turbine	Cone WGA	Bell WGA
1	11.23	16.96	18.42	32	24.94	41.90	41.90
2	23.26	34.66	35.13	33	7.40	11.70	11.40
3	19.44	28.96	32.27	34	5.08	7.92	8.53
4	17.87	28.60	28.06	35	4.09	6.14	6.22
5	23.40	37.67	36.97	36	1.45	2.21	2.41
6	19.55	29.13	32.65	37	23.53	35.53	35.77
7	8.43	13.07	13.91	38	14.90	23.69	23.09
8	10.45	16.09	17.24	39	23.40	34.16	39.08
9	21.50	31.82	35.04	40	4.45	7.03	7.08
10	3.76	6.01	5.75	41	12.77	18.65	20.69
11	24.05	39.20	40.40	42	24.00	39.60	38.16
12	19.06	31.83	28.21	43	1.16	1.73	1.88
13	9.19	13.97	15.35	44	19.08	28.05	31.67
14	6.29	9.49	9.87	45	8.70	13.75	13.40
15	17.43	26.84	26.14	46	6.55	9.96	10.81
16	7.94	12.07	11.99	47	15.70	23.40	23.87
17	11.27	18.49	16.57	48	3.62	5.25	6.02
18	3.22	4.96	4.70	49	9.75	14.92	16.39
19	1.86	2.78	2.82	50	24.02	37.24	39.16
20	24.90	41.08	36.35	51	6.13	9.87	8.95
21	14.81	23.55	22.36	52	2.84	4.32	4.15
22	6.06	9.94	9.15	53	18.34	26.60	28.06
23	10.58	15.66	15.45	54	23.47	36.14	38.95
24	11.39	18.33	17.99	55	11.48	19.05	18.71
25	19.39	32.19	31.61	56	18.99	29.06	28.30
26	17.18	25.25	27.49	57	11.95	18.28	17.68
27	21.92	32.66	35.29	58	15.59	25.26	24.95
28	4.94	7.22	7.61	59	15.90	23.86	24.81
29	9.04	13.65	14.37	60	4.61	7.47	7.70
30	5.44	8.70	8.10	61	11.63	16.98	17.68
31	16.11	26.74	23.51	62	19.33	29.96	30.92

Table 15. *Power Output Data during Experiments*

	Wind Speed (mph)	400W Power Output	Cone PO-400W	Bell PO-400W
1	11.23	400	400.00	400.00
2	23.26	400	400.00	400.00
3	19.44	400	400.00	400.00
4	17.87	400	400.00	400.00
5	23.40	400	400.00	400.00
6	19.55	400	400.00	400.00
7	8.43	202.23	400.00	400.00
8	10.45	384.40	400.00	400.00
9	21.50	400.00	400.00	400.00
10	3.76	17.90	73.30	64.10
11	24.05	400.00	400.00	400.00
12	19.06	400.00	400.00	400.00
13	9.19	262.03	400.00	400.00
14	6.29	83.74	288.32	324.08
15	17.43	400.00	400.00	400.00
16	7.94	168.86	400.00	400.00
17	11.27	400.00	400.00	400.00
18	3.22	11.27	41.16	35.07
19	1.86	2.16	7.28	7.58
20	24.90	400.00	400.00	400.00
21	14.81	400.00	400.00	400.00
22	6.06	75.12	331.34	258.62
23	10.58	386.87	400.00	400.00
24	11.39	400.00	400.00	400.00
25	19.39	400.00	400.00	400.00
26	17.18	400.00	400.00	400.00
27	21.92	400.00	400.00	400.00
28	4.94	40.74	126.78	148.79
29	9.04	248.87	400.00	400.00
30	5.44	54.16	221.82	179.15
31	16.11	400.00	400.00	400.00
32	24.94	400.00	400.00	400.00
33	7.40	136.87	400.00	400.00

34	5.08	44.15	167.60	209.33
35	4.09	23.13	78.07	81.23
36	1.45	1.04	3.64	4.74
37	23.53	400.00	400.00	400.00
38	14.90	400.00	400.00	400.00
39	23.40	400.00	400.00	400.00
40	4.45	29.74	117.32	119.56
41	12.77	400.00	400.00	400.00
42	24.00	400.00	400.00	400.00
43	1.16	0.53	1.76	2.26
44	19.08	400.00	400.00	400.00
45	8.70	222.17	400.00	400.00
46	6.55	94.94	333.40	400.00
47	15.70	400.00	400.00	400.00
48	3.62	16.05	48.92	73.40
49	9.75	312.82	400.00	400.00
50	24.02	400.00	400.00	400.00
51	6.13	77.64	324.01	241.62
52	2.84	7.73	27.15	24.06
53	18.34	400.00	400.00	400.00
54	23.47	400.00	400.00	400.00
55	11.48	400.00	400.00	400.00
56	18.99	400.00	400.00	400.00
57	11.95	400.00	400.00	400.00
58	15.59	400.00	400.00	400.00
59	15.90	400.00	400.00	400.00
60	4.61	32.99	140.27	153.67
61	11.63	400.00	400.00	400.00
62	19.33	400.00	400.00	400.00

Table 16. *Wind Data for September 2013* (Modified from IEC, 2013)

Relative Frequency: Sep					
mph	m/s	No. of Hours	mph	m/s	No. of Hours
1	0.45	2	26	11.62	2
2	0.89	7	27	12.07	1
3	1.34	13	28	12.52	1
4	1.79	20	29	12.96	0
5	2.24	27	30	13.41	0
6	2.68	34	31	13.86	0
7	3.13	41	32	14.31	0
8	3.58	46	33	14.75	0
9	4.02	51	34	15.2	0
10	4.47	54	35	15.65	0
11	4.92	55	36	16.09	0
12	5.36	54	37	16.54	0
13	5.81	52	38	16.99	0
14	6.26	48	39	17.43	0
15	6.71	43	40	17.88	0
16	7.15	38	41	18.33	0
17	7.6	32	42	18.78	0
18	8.05	27	43	19.22	0
19	8.49	21	44	19.67	0
20	8.94	16	45	20.12	0
21	9.39	12	46	20.56	0
22	9.83	9	47	21.01	0
23	10.28	6	48	21.46	0
24	10.73	4	49	21.9	0
25	11.18	3	50	22.35	0

Table 17. *Wind Data for October 2013*(Modified from IEC, 2013)

Relative Frequency: Oct

mph	m/s	No. of Hours	mph	m/s	No. of Hours
1	0.45	2	26	11.62	4
2	0.89	5	27	12.07	3
3	1.34	10	28	12.52	2
4	1.79	16	29	12.96	1
5	2.24	22	30	13.41	1
6	2.68	28	31	13.86	0
7	3.13	34	32	14.31	0
8	3.58	40	33	14.75	0
9	4.02	45	34	15.2	0
10	4.47	49	35	15.65	0
11	4.92	51	36	16.09	0
12	5.36	52	37	16.54	0
13	5.81	52	38	16.99	0
14	6.26	50	39	17.43	0
15	6.71	47	40	17.88	0
16	7.15	43	41	18.33	0
17	7.6	39	42	18.78	0
18	8.05	34	43	19.22	0
19	8.49	29	44	19.67	0
20	8.94	24	45	20.12	0
21	9.39	19	46	20.56	0
22	9.83	15	47	21.01	0
23	10.28	11	48	21.46	0
24	10.73	8	49	21.9	0
25	11.18	6	50	22.35	0

Table 18. *Wind Data for November 2013*(Modified from IEC, 2013)

Relative Frequency: Nov					
mph	m/s	No. of Hours	mph	m/s	No. of Hours
1	0.45	3	26	11.62	9
2	0.89	7	27	12.07	7
3	1.34	12	28	12.52	6
4	1.79	17	29	12.96	4
5	2.24	22	30	13.41	3
6	2.68	26	31	13.86	3
7	3.13	31	32	14.31	2
8	3.58	35	33	14.75	1
9	4.02	38	34	15.2	1
10	4.47	40	35	15.65	1
11	4.92	42	36	16.09	0
12	5.36	42	37	16.54	0
13	5.81	42	38	16.99	0
14	6.26	42	39	17.43	0
15	6.71	40	40	17.88	0
16	7.15	38	41	18.33	0
17	7.6	35	42	18.78	0
18	8.05	32	43	19.22	0
19	8.49	29	44	19.67	0
20	8.94	26	45	20.12	0
21	9.39	22	46	20.56	0
22	9.83	19	47	21.01	0
23	10.28	16	48	21.46	0
24	10.73	14	49	21.9	0
25	11.18	11	50	22.35	0

APPENDIX B

RELATED FIGURES

Figure 23. Wind Velocity, Experiment 1

(Modified The Weather Channel, 2013)

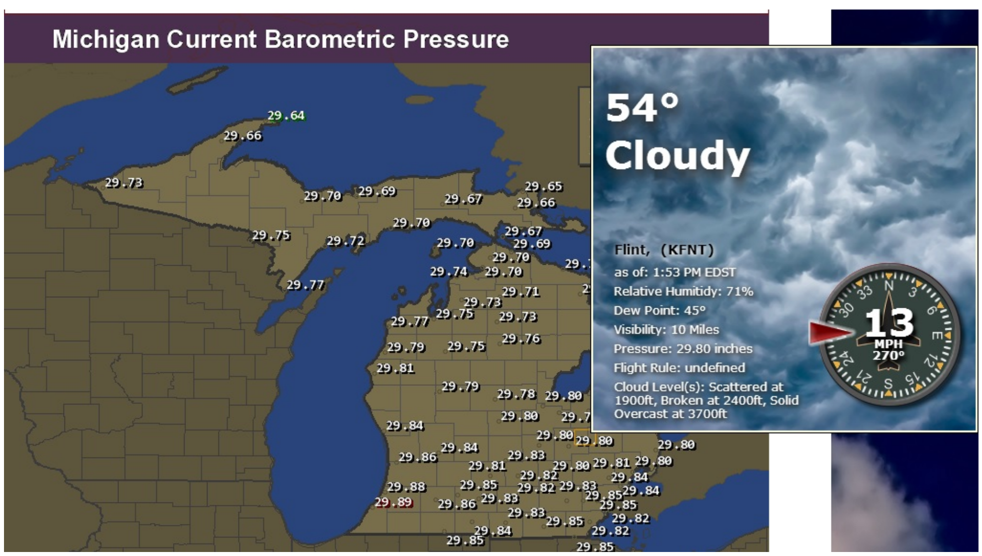


Figure 24. Wind Velocity, Air pressure
(Modified The Weather Channel, 2013)

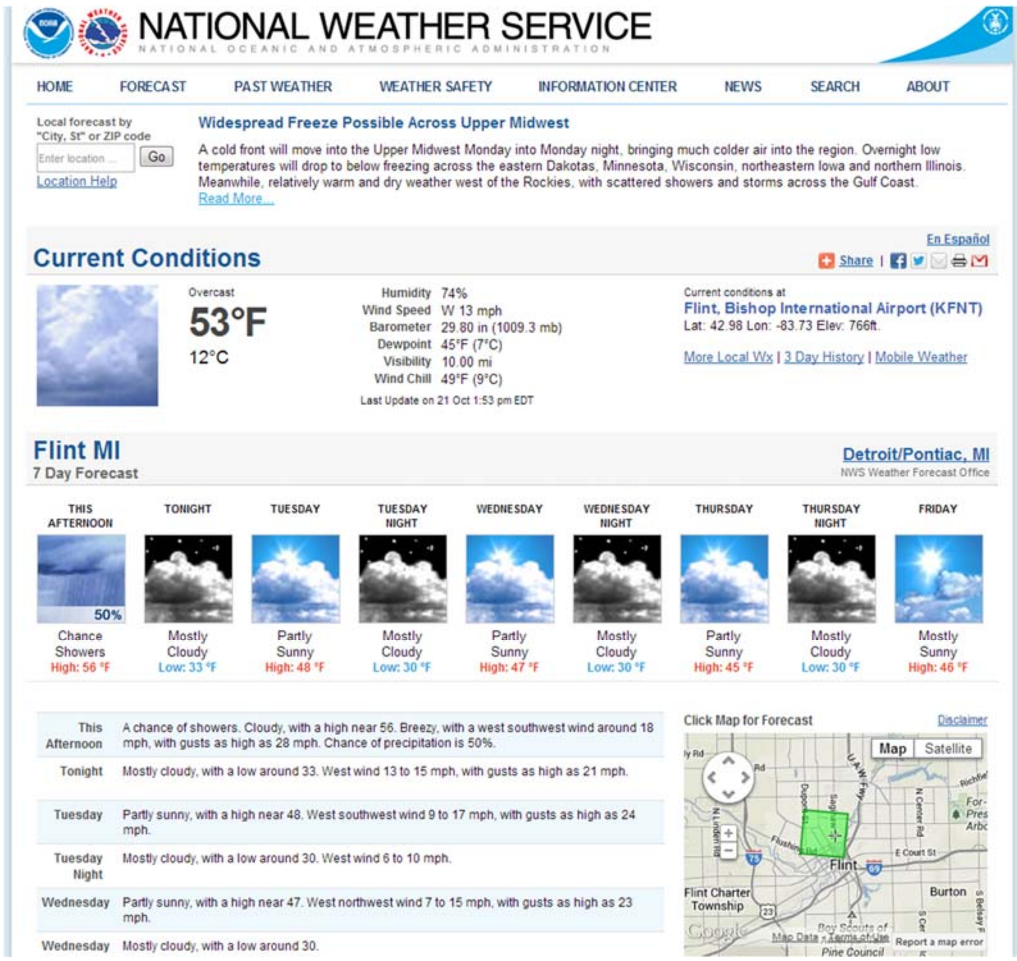


Figure 25. Wind Velocity, Experiment 2 (Modified NWS, 2013)

Daily Weather History & Observations

2013	Temp. (°F)			Dew Point (°F)			Humidity (%)			Sea Level Press. (in)			Visibility (mi)			Wind (mph)			Precip. (in)	Events
Oct	high	avg	low	high	avg	low	high	avg	low	high	avg	low	high	avg	low	high	avg	high	sum	
1	77	63	48	61	56	46	93	74	54	30.01	29.96	29.91	10	8	3	18	9	26	0.00	
2	80	65	49	59	49	36	93	57	21	30.09	30.03	29.93	10	8	2	10	4	16	0.00	Fog
3	83	66	49	64	57	44	87	69	51	30.07	30.00	29.91	10	10	8	14	6	21	0.00	
4	81	74	67	65	64	63	87	71	54	30.05	29.99	29.93	10	10	5	12	5	16	0.05	Rain , Thunderstorm
5	74	70	65	67	64	63	93	86	79	30.05	29.98	29.86	10	6	2	13	7	17	0.35	Rain , Thunderstorm
6	72	63	53	67	61	51	93	81	68	29.85	29.74	29.65	10	8	1	18	9	24	0.39	Rain
7	62	55	47	51	46	41	93	73	52	30.08	29.80	29.69	10	10	5	21	10	25	0.05	Rain
8	69	53	37	47	42	37	96	68	39	30.29	30.26	30.22	10	10	10	13	5	18	0.00	Fog
9	72	58	44	51	44	41	93	67	40	30.34	30.28	30.23	10	10	9	12	5	16	0.00	
10	72	56	40	52	43	40	96	65	34	30.25	30.21	30.15	10	7	0	10	3	-	0.00	Fog
11	74	55	36	48	41	37	100	65	29	30.19	30.13	30.09	10	10	7	12	3	-	0.00	
12	77	61	45	60	51	43	100	72	43	30.12	30.09	30.04	10	8	0	16	6	21	0.00	Fog
13	68	56	44	57	46	39	89	63	37	30.38	30.25	30.10	10	10	9	16	8	20	0.00	
14	65	50	34	43	39	33	92	65	37	30.45	30.38	30.31	10	10	7	13	4	15	0.00	
15	68	52	36	59	48	34	100	80	59	30.29	30.05	29.81	10	7	0	18	9	22	0.15	Fog , Rain
16	62	57	51	59	48	44	90	76	62	29.90	29.84	29.80	10	9	5	20	10	25	T	
17	53	49	44	50	47	43	89	86	83	29.91	29.84	29.74	10	6	2	20	7	24	0.29	Rain
18	64	53	42	43	40	36	89	63	36	29.91	29.87	29.83	10	9	6	17	9	23	0.00	
19	54	47	40	43	40	33	92	71	50	29.88	29.81	29.73	10	8	2	24	8	28	0.19	Rain
20	57	49	41	42	38	36	89	68	47	29.92	29.86	29.80	10	10	10	18	8	26	T	Rain
21	57	52	48	47	44	40	86	71	44	29.83	29.81	29.80	10	10	8	15	11	22	0.04	Rain

Comma Delimited File

Figure 26. Wind Data for October, Flint, MI (Modified NWS, 2013)

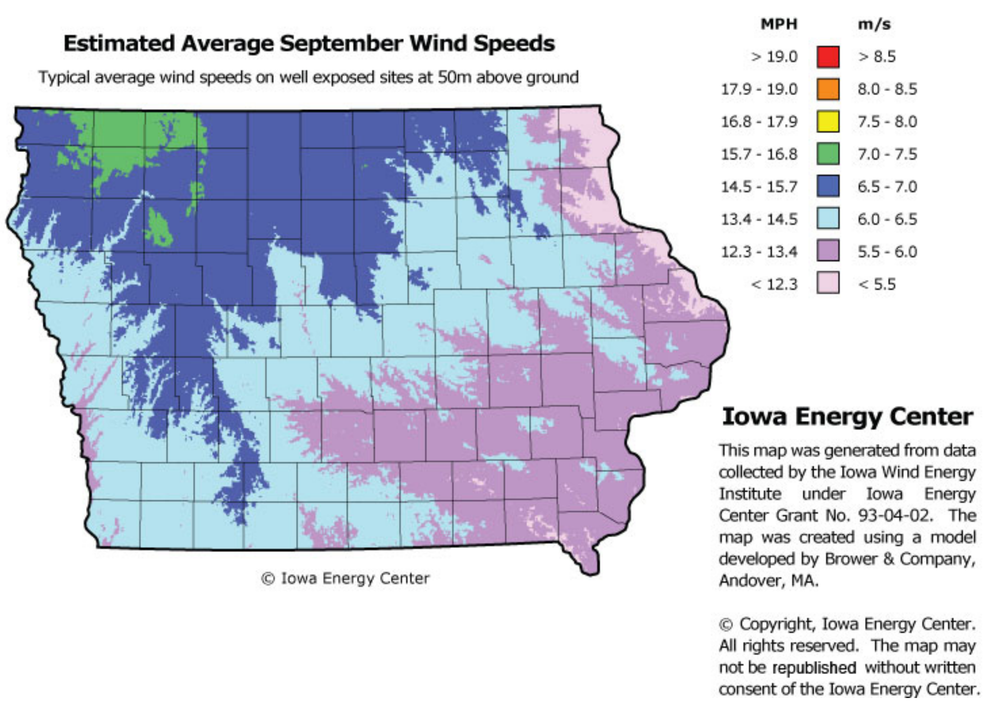


Figure 27. Wind Data for September, Iowa, (Modified IEC, 2013)

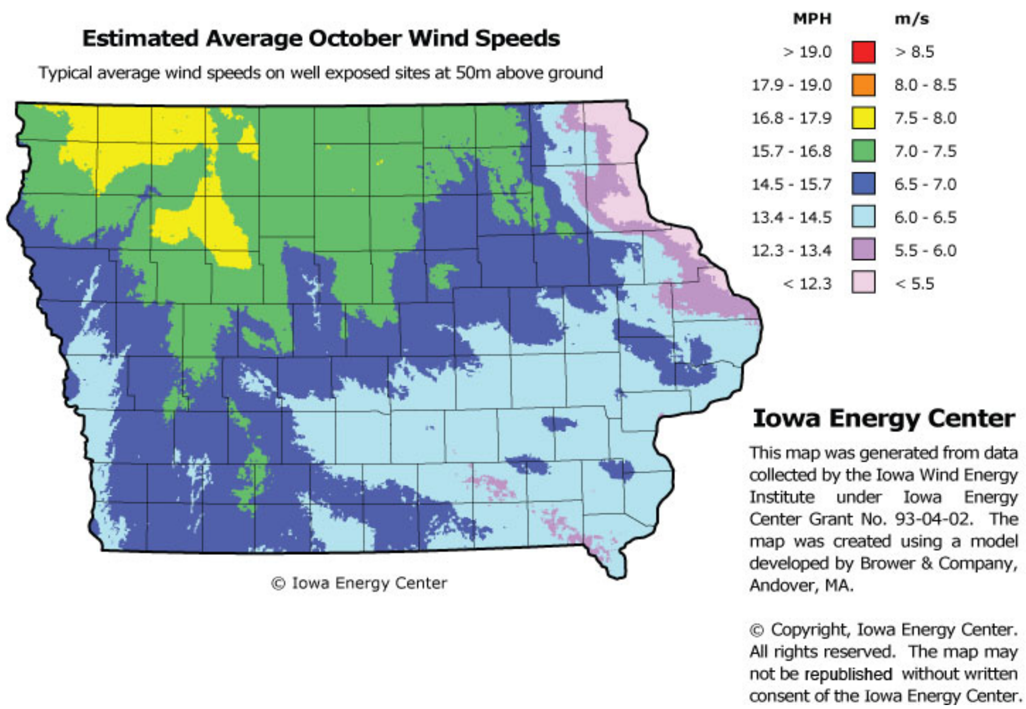


Figure 28. Wind Data for October, Iowa (Modified IEC, 2013)

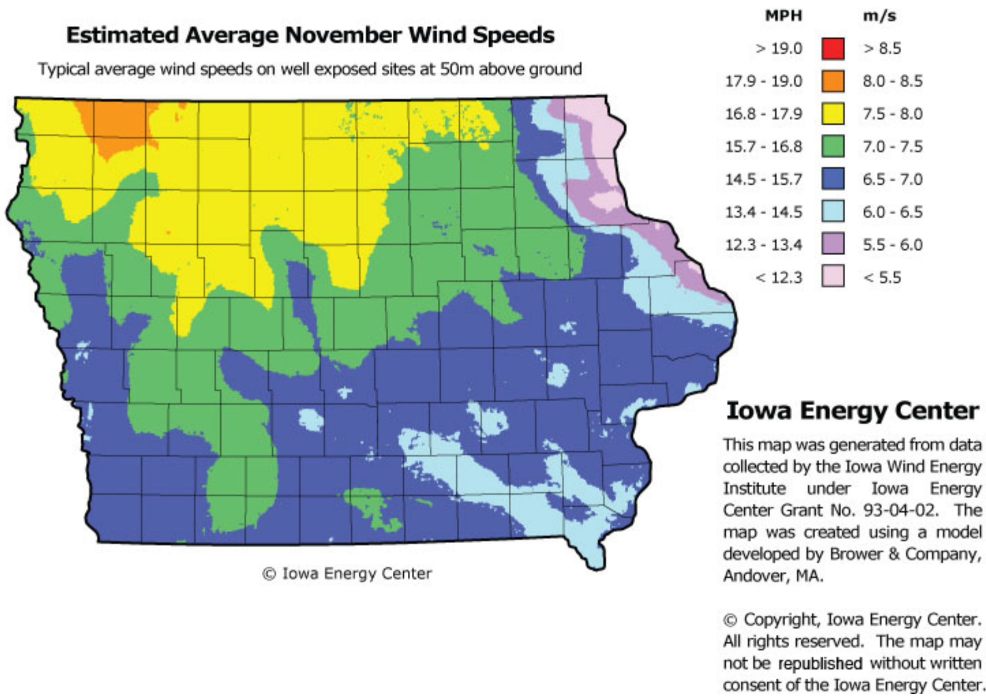


Figure 29. Wind Data for November, Iowa (Modified IEC, 2013)

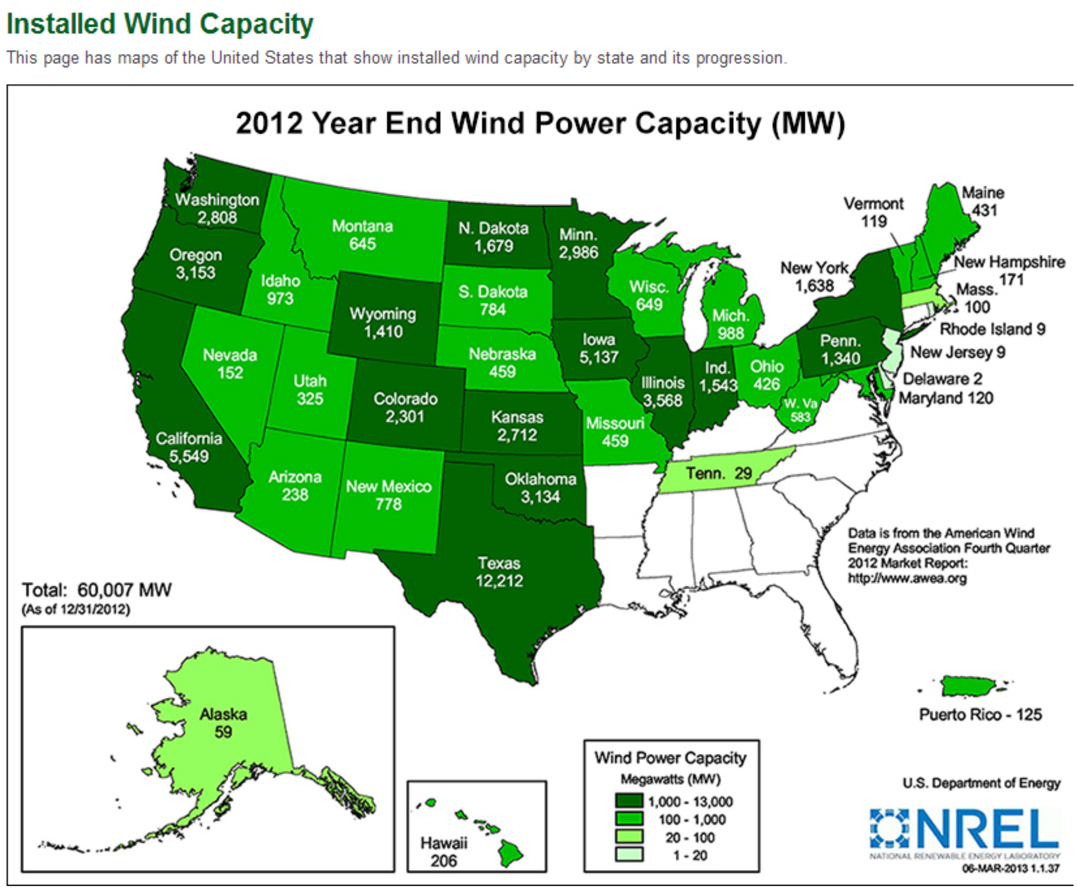


Figure 30. Annual Wind Data for Iowa, 2013 (Modified DOE, 2013)

UROP
UNDERGRADUATE RESEARCH OPPORTUNITY PROGRAM

Office of Research and Sponsored Programs
4203 William S. White Building
Telephone: 810-762-3383
Fax: 810-766-6791
www.umflint.edu/research/UROP

September 30, 2013

To: Ulan Dakeev; Instructor, CSEP

RE: UROP Proposal

Congratulations! Your project **"Analysis of Wind Tunnel Attachment on a Small Scale Wind Turbine"** has been accepted as a UROP Project for the 2013-2014 academic year. Your project number is UR188. As you begin working with your student(s), please make note of the following guidelines:

Students can earn a maximum of **$500** during the fall and winter UROP periods and up to **$250** during the spring and summer UROP periods. Students are paid bi-weekly at an hourly rate you negotiate with them (between $8 – 15 per hour). Any work your student(s) perform on your project after their funds have been exhausted will not be paid by UROP.

Before funds are released to your student(s), they are required to complete the following steps:

- Attend a mandatory orientation, where we discuss the application process, timesheets, and other important matters,
- Have certification in at least the "Foundations of Good Research Practice" module in PEERRS (we encourage you to work with your student(s) to determine which additional module(s) may be appropriate for your project);
- Complete a **UROP Contract**. This form indicates the hourly rate and other terms/conditions associated with your project; and
- Complete the University employment process. **It is a violation of University AND Federal guidelines for students to begin ANY work on the project BEFORE they have completed the University's employment process. If you are in non-compliance with these guidelines and the University is audited, your department will be charged for any fines and penalties that incur. Once the student has been authorized to work, you will be notified by UROP.**

The steps new UROP students must take can be found here:
http://www.umflint.edu/research/student_programs/UROP/12-steps.htm.

UROP will provide administrative oversight, especially with payroll matters. Timesheets *must* be signed by you or a designated signer and submitted to our office by each due date (arrangements can also be made for electronic approval of hours). UROP will notify you and your student(s) as to the funding remaining for each semester. *Student funds left unspent by the end of each UROP semester will be swept and reapplied back to the UROP account for the next semester.* As a faculty sponsor, you will have the opportunity to extend your project after each semester.

Lastly, we would encourage you to work closely with your student(s) in developing a research project to submit at the annual *Meeting of Minds Undergraduate Research Conference* (MOM) and/or the UM-Flint Student Research Conference (SRC). Times and dates for each event will be announced soon.

Please feel free to refer to the UROP Faculty Handbook (www.umflint.edu/research/UROP under "Faculty Resources") for additional information not included in this letter.

Please sign and return this letter to Andre Louis, 4203 WSWB. With your signature, you are agreeing to the conditions outlined above. Please retain a copy for your records.

Ulan Dakeev	10/04/2013
Faculty sponsor signature	Date

Figure 31. Undergraduate Research Approval Letter