Analysis of Wind-Power Generation with Wind-Guide Attachment

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Abstract

This study presents an empirical method for developing a new approach using a wind tunnel apparatus 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. Wind power characteristics that indicate power output versus wind velocity were obtained by performing a number of case studies that included normal operation of the experimental wind turbine at variable values of wind velocity with and without the proposed wind tunnel. The statistical t-test and one-way ANOVA analyses resulted in a 60% increase in wind power output with the use of the custom-constructed design.

Introduction

The use of wind energy continues to grow significantly around the world. Along with solar, wind dominates the investment in new renewable capacity and is becoming a main form of renewable energy. For this reason, the development of wind turbines has been in great demand to enhance usage and efficiencies. Unfortunately, wind turbines have limited features in low-level efficiencies.

Wind is the process whereby the movement of air flows from an area of high pressure to an area of low pressure. This course of movement exists because the heat of the sun is unevenly distributed along the surface of the Earth. When hot air rises, the cooler air travels into the vacuum. As long as the sun continues to shine, the wind will continue to blow. With that, wind power is produced. A wind turbine will capture the energy of the movement of air and convert that to power. The blades in the wind turbine are aerodynamically designed to spin when the wind is blowing [1].

An experiment was carried out in Iran by Pourrajabian et al. to examine the effects of air density on the performance of a small wind-turbine blade. Their research aimed to improve the performance of the turbine at low wind speeds by considering factors involving air density, altitudes, and then optimizing the structure of the blade. The wind turbine was tested in four different locations in Iran with altitudes up to 3000 m. The results showed that the blade, which was designed to be optimized at sea level, degrades in other locations and that degradation is more significant for the initial performance than the power coefficient. The blade of the wind turbine was adjusted in two steps to develop optimization when located at different altitudes. Adjustments to blade geometry were made to optimize for air density at elevations that surges the power coefficient and starting time. Another step was to optimize the tip speed ratio along with the blade. Optimizing the blade aimed to make the most of the output power [2].

Another study by Jureczko, Pawlak, and Mezyk was optimization of wind turbine blades. In their research, the authors determine the optimal shape of a blade and the optimal composite material. The goal was to advance a computer database package that would allow optimization of wind turbine blades considering a number of measures the properties of the blade, aerodynamic loads, status of the load on the blade, and the selection of composite materials for the blade [3].

Previous studies encouraged this specific study to initialize the design of the wind tunnel attachment. The cone was designed and inserted to allow for a greater power output, shaped and constructed to allow the incoming air to flow from the wind turbine hub toward the tips of the wind turbine blades. To increase and maximize the low wind speeds going into the wind turbine, essentially, a custom-designed, cone-shaped wind guide attachment was introduced.

In this custom-designed wind tunnel attachment, the wind guide apparatus shown in Figure 1 is attached to the front of the small-scale wind turbine. It is fit in so that the enclosed space inside the wind tunnel will compose the wind when entering the tunnel, allowing a higher wind output exiting it. Power produced by a wind turbine depends on the turbine and the parameters of the wind. Several other factors should have been accounted for in this experiment, but sometimes detailed data is lacking, such as the streamline flow of the wind.

To avoid some limitations, choosing the appropriate location to test the wind tunnel is crucial. A high, flat, and empty location is important because the properties and speeds of the wind must be exact to accurately measure the wind velocities coming in and out of the wind tunnel. In this case, turbulence, wind shear, and acceleration are considered. Being in a high area will allow the best chances of receiving wind speed because there are no buildings causing turbulence and decreasing the output of wind power from the wind turbine. Also, wind slows down at lower elevations [4].

The purpose of this study is to experiment with a wind guide apparatus to the tunnel attachment to observe the differences in wind velocities going from the inlet to the outlet. This will help determine a way to develop an increased power output from the wind turbine with low wind speeds going into the turbine. This paper will propose a solution in wind turbines producing power at low-wind velocities.

Figure 1. Wind tunnel attachment (WTA)

Methodology

The study consisted of a set of procedures that would test and analyze a wind turbine attachment to assess the performance of an experimental wind turbine at different wind velocities. A custom constructed wind tunnel attachment was transported to a high elevation field for the experiment. Construction was contracted to an outside vendor with a specification that the inlet section (larger diameter) be 1.45 times larger than the tube (smaller diameter). Additionally, the inlet section was constructed with a 30º angle from the horizontal surface of the tube. This angled section was not tested to compare how different angles would behave in terms of wind flow rate. Two anemometers were placed to measure the wind velocities at the inlet and outlet sections of the WTA shown in Figure 2.

The results of the 45 data points obtained were recorded into the SPSS Statistics 20 package. A t-test and analysis of variance were performed to observe the level of significance. The location that was chosen for the testing site was at the University of Michigan, Flint, on the top level of the East parking garage. The average wind velocity at the test site was 10 mph annually. The height of the testing point, approximately 30 feet above ground level, granted the team access to optimal wind conditions.

Experimental Analyses

The controllable variable during the field test was the wind guide apparatus mounted inside the wind tunnel attachment. The Pearson correlation coefficient (R) in Table 1 was calculated to 0.963, where 1 is a perfect positive correlation. This shows a consistent wind velocity increase as wind exits the attachment.

In this case, the wind-in (x-axis) is compared to the wind-out (y-axis) calculated with the number of sample data (n). Based on the results from the data collected, a strong correlation (0.963) exists between the velocity of the wind-in and the velocity of the wind-out when the wind guide apparatus is used. This reveals that the group is receiving consistent results from wind-out data. R^2 is a statistical measure of how close the data are to the fitted regression line. It is also known as the coefficient of determination. Figure 3 shows the R^2 value for the wind velocity. The authors' first indicator of generalizability is the adjusted R^2 value, which is adjusted for the number of variables included in the regression equation. The adjusted R^2 is used to estimate the expected shrinkage in R^2 that would not generalize to the population because the solution is over-fitted to the data set by including too many independent variables [5].

Table 1. Model Summary

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate
1	.963	.927	.926	1.31598

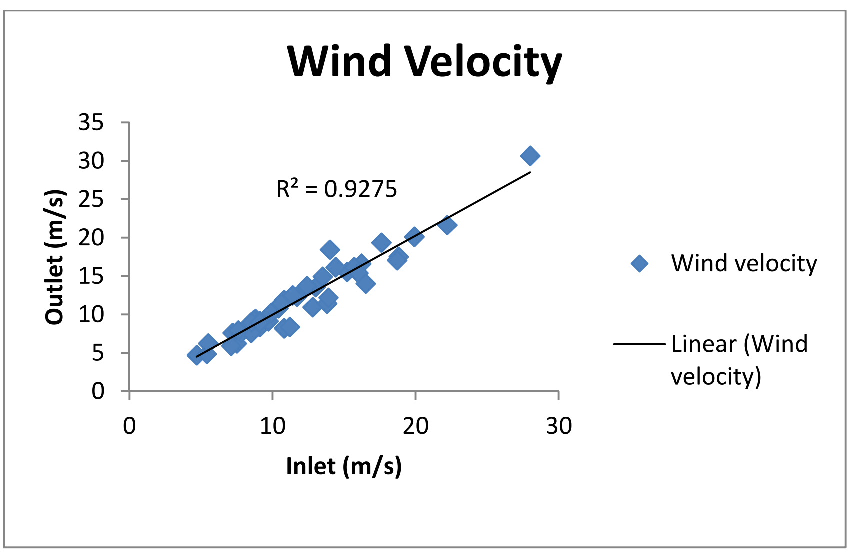

Figure. 2 Wind velocity

The test data points were used to perform an independent sample t-test Table 3. Levene's test showed 0.034, less than p=0.05, to indicate the consideration of unequal variances. Calculated t-test analysis for the difference of the wind velocity change in relation to incoming wind speed influenced by the wind guide attachment to support the study objective is presented in Table 2. The “wind-in” and “wind-out” categories represent the incoming and outgoing wind respectively.

Table 2. Group statistics

	Groups	N	Mean	Std. Deviation	Std. Error Mean
Wind Data	Wind-In	45	7.8578	3.38791	0.50504
	Wind-Out	45	11.9622	4.82999	0.72001

The t-test in Table 3 yields the mean of wind-in approximately 1 =7.85 mph, while the mean of wind-out resulted in approximately 11.9 mph. The p-value obtained from the analysis was p=0.034, less than the alpha level of 0.05, which indicated that there is significant difference between the average means of the wind velocities with the use of the custom-constructed WTA with the cone shaped wind guide attachment and uncontrolled wind speed.

Table 3. Wind velocities

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
WindData	Equal variances assumed	4.629	.034	-4.667	88	.000	-4.10444	.87948	-5.85222	-2.35667
	Equal variances not assumed			-4.667	78.858	.000	-4.10444	.87948	-5.85505	-2.35384

Individual wind velocities can be better visualized in Figure 3.

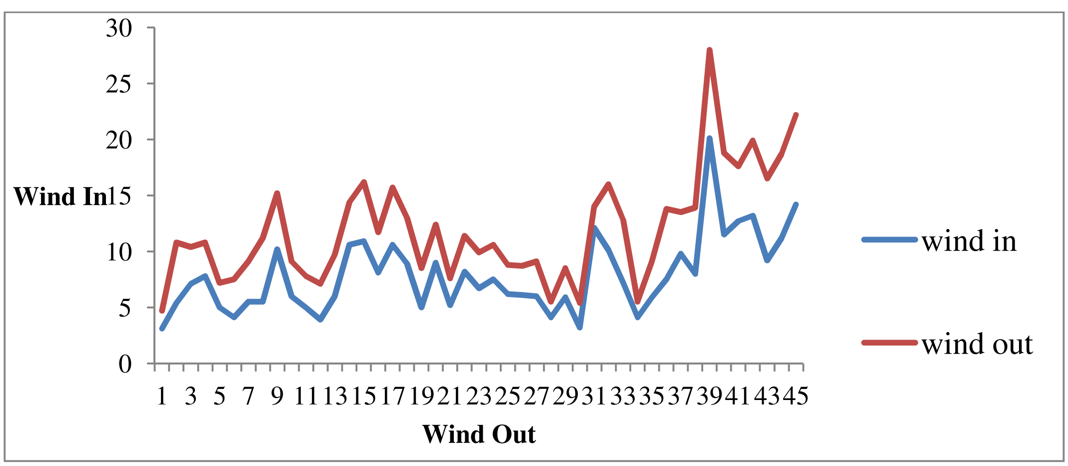

Figure 3. Individual wind velocities

An ANOVA test was conducted to examine the effect of the WTA on differences in wind velocity changes for statistical significance. Table 4 below shows the ANOVA test results

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for the wind velocity output to validate t-test analysis. Table 4 shows that there is still a significant difference between the incoming and outgoing wind velocity means.

Table 4. One-way ANOVA

Wind Data	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	379.045	1	379.045	21.780	.000
Within Groups	1531.496	88	17.403		
Total	1910.541	89			

The F-statistic in Table 4 is the ration of the sum of squares between the samples divided by the degrees of freedom between all divided by the sum of squares within divided by the degrees of freedom of the sum of squares within. Since the numerator is much larger than the denominator, leaving us with a large F-statistic, this indicates that the variation in the data is due mostly to the differences of the actual means and less to the actual variation within the means [6].

Figure 4. Wind data collection

Conclusion

Based on the investigation that was conducted to evaluate the relationship between wind velocity outputs using a custom-designed WTA with wind guide attachment, a consistent increase in wind velocity was produced. According to the data accumulator ran through Microsoft Excel the mean wind velocity increase of approximately 60% was calculated based on the 45 wind data points collected at the University of Michigan, Flint, on the top level of the East parking garage. The calculated velocity increase confirms the hypothesis that containing wind particles and guiding them in a uniform direction will create a less turbulent wind flow that will, in turn, enable a uniform flow. This flow allows the wind particles to repel in the same direction, inducing a greater wind velocity extracted from the WTA. This greater wind velocity generation will decrease the power generation starting point for power generating wind turbines.

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Biographies

ULAN DAKEEV received his bachelor's degree in Industrial Engineering in Georgia, a master's in Industrial Management in Iowa, and a doctorate in Technology in Iowa. He worked as a continuous improvement design engineer for John Deere Waterloo Works for 3.5 years. He is currently a faculty member in the Engineering Department at the University of Michigan, Flint.

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