ANALYSIS OF WIND-POWER GENERATION WITH A WIND-GUIDE ATTACHMENT

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Abstract

In this study, the authors developed a new empirical method for a wind tunnel apparatus that can be 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. A number of case studies were performed in order to obtain power output versus wind velocity characteristics. The case studies included normal operation of the 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 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 the main form of renewable energy. For this reason, the development of wind turbines has been in great demand to enhance the usages and efficiencies. Unfortunately, wind turbines have limited features in low-level efficiencies [1]. Wind is the process whereby the movement of air flows from an area of high pressure to an area of low pressure [2]. 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 of the wind turbine are aerodynamically designed to spin when wind is blowing.

A case study was carried out in Iran by Pourrajabian et al. [3], where they structured an experiment on the effects of air flow on the performance of an experimental wind turbine blade. That study aimed to improve the performance of the turbine at low wind speeds by considering factors such as density and 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, that was designed to be optimized for sea level, degrades for other locations and that degradation was more significant for the initial performance than the power coefficient. The blade of the wind turbine was adjusted in two steps in order to develop optimization at varying altitudes. Adjustments to its geometry were made on the blade to optimize it for air density at elevations for power coefficient at the start of rotation. 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.

Another study by Jureczko et al. [4] was an optimization of wind turbine blades. In their research, the authors determined 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. They considered the properties of the blade, aerodynamic loads, status of the load on the blade, and the selection of composite materials of the blade. Previous studies encouraged this current study to initialize the design of the wind tunnel attachment. The cone was designed and inserted to allow for a greater power output. The cone was shaped and constructed to allow the incoming air to flow from the wind turbine hub toward the tips of the wind turbine blades. In order to increase and maximize the low wind speeds going into the wind turbine, a custom-designed cone-shaped wind guide attachment was introduced.

In this customized design of a wind tunnel attachment, a wind guide apparatus, shown in Figure 1, was attached to the front of the small-scale wind turbine. It was fit in so that the enclosed space inside the wind tunnel would compose the wind when coming into the wind tunnel, allowing a higher wind output going out from it. Power produced by a wind turbine depends on the turbine and the parameters of the wind [5]. Several other factors needed to be accounted for in this experiment, but sometimes detailed data are not available, such as the streamline flow of the wind.

To avoid some limitations, the need to choose the appropriate location to test the wind tunnel was crucial [6]. A high, flat, and empty location was important because the properties and speeds of the wind must be exact in order to accurately measure the wind velocities entering and exiting the wind tunnel. In this case, turbulence, wind shear, and acceleration were considered. Being in a higher wind speed area would allow the best chances of receiving higher wind speeds because there would be no buildings causing turbulence and decreasing the output of wind power from the wind turbine. Also, wind slows down when it is close to the ground [7]. The purpose of this current study was to experiment with a wind guide apparatus to the wind tunnel attachment in order to observe the differences in wind velocities going from the inlet to the outlet. This would help determine a way to develop increased power output from the wind turbine with lower wind speeds going into the turbine. The proposal, then, is a solution to wind turbines producing power at low–wind velocities.

Methodology

The current 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 customized wind tunnel attachment was transported to a highly elevated field for the experiment. Construction was contracted to an outside vendor with the specification that the inlet section (larger diameter) be 1.45 times larger than the tube (smaller diameter). Additionally, the inlet section was constructed at a 30-degree 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 in order to measure the wind velocities at the inlet and outlet sections of the WTA (see Figure 2).

Figure 2. Wind Data Collection

The results of the 45 data points obtained were recorded into IBM's 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 thirty feet above ground level, granted the team access to optimal wind conditions.

Figure 1. Wind Tunnel Attachment (WTA)

Experimental Analyses

The controllable variable during the field test was the wind guide apparatus mounted inside the wind tunnel attachment. A Pearson Correlation Coefficient (R) in Table 1 was calculated to be 0.963, where 1.0 is a perfect positive correlation. This showed a consistent wind velocity increase as wind exited the attachment [8]. In this case, the "Wind In" (x-axis) was 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) existed between the velocity of the wind- in and the velocity of the wind out, when the wind guide apparatus was used. This reveals that the group was receiving consistent results from wind out data. R^2 is a statistical measure of how close the data are to the fitted regression line. Table 1 shows the model summary in which the standard deviation error of the estimate was 1.31598. The R^2 value is also known as the coefficient of determination; Figure 3 shows the R^2 value for the wind velocity. The adjusted R^2 value indicates the generalizability of variables in the regression equation [8].

Table 1. Model Summary

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

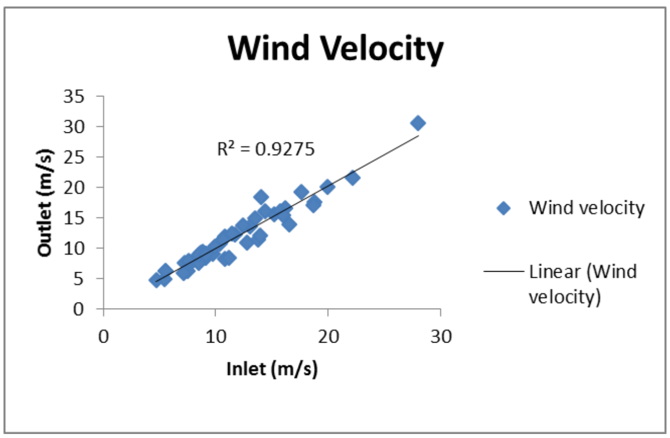

Figure 3. Wind Velocity

Table 2 shows the collection of wind data for all 45 points. It was sectioned in order to portray the mean, standard deviation, and standard error mean of the velocity for wind going in and wind going out. The test data points were used to perform an independent sample t-Test (see Table 3). The Levene's Test showed a value of 0.034, less than p=0.05, to indicate the consideration of unequal variances. The 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 below. The categories wind in and wind out represent the incoming and outgoing wind, respectively [9].

Table 2. Group Statistics for Wind Data

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

Table 3. Levene's Test for Equality of Variances

Levene's Test for Equality of Variances	F	Sig.
Equal Variances Assumed	4.629	0.034
Equal Variances not assumed		0.034

The t-Test in Table 4 shows that the mean of the wind in was approximately Mean 1 = 7.85 mph, while the mean of wind out was approximately Mean 2 = 11.9 mph. Table 5 represents the chosen confidence interval of 95%. The p-value obtained from the analysis was p = 0.034, less than the alpha level of 0.05, which indicated that there was a significant difference between the average means of the wind velocities with the use of the custom WTA with the cone-shaped wind guide attachment and uncontrolled wind speed [10]. Figure 2 displays a better visual of individual wind velocities, taken at the time of data collection.

Table 4. t-Test for Equality of Means

t-Test for equality of means	t	df	Sig. (2-tailed)	Mean difference	Std. error
Equal variances assumed	-4.667	88	.000	-4.10444	.8794
Equal variances not assumed	-4.667	78.858	.000	-4.10444	.8794

Table 5. t-Test at 95% Confidence Interval of Difference

t-Test for equality of means	Lower	Upper
Equal variances assumed	-5.85222	-2.35667
Equal variances not assumed	-5.85505	-2.35384

A one-way analysis of variance was conducted in order to examine the effect of the WTA on differences in wind velocity changes for statistical significance. Table 6 shows the one way analysis of variance (ANOVA) test results for the wind velocity output to validate the t-Test analysis. The ANOVA table shows that there was still a significant difference between the incoming and outgoing wind velocity means. The F-statistic (F) of Table 6 is the ratio 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, one can conclude 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 [11].

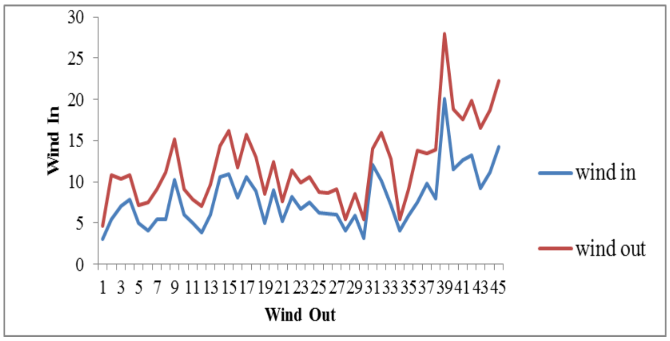

Figure 4. Comparison of Wind In and Wind Out

Table 6. 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			

Conclusions

Based on the investigation that was conducted to evaluate the relationship between wind velocity outputs using a custom-designed wind tunnel apparatus (WTA) with wind guide attachment, a consistent increase in wind velocity was produced. According to the data accumulator run 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, which will in turn enable a more uniform flow. This uniform flow will allow 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 a power-generating wind turbine.

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