ANALYSIS OF WIND POWER GENERATION WITH APPLICATION OF WIND TUNNEL ATTACHMENT

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ABSTRACT

This study presents an empirical method for developing a new approach in which a wind tunnel apparatus is used to improve the power generation efficiency of a small wind turbine. A custom-designed wind tunnel attachment was used to evaluate the performance of the wind turbine. The experimental investigation consists of measuring upstream and downstream wind velocities as well as power output from the wind tunnel attachment. The power generated by the wind turbine at different wind velocities was used to develop a characteristic performance curve. The case studies included normal operation of the experimental wind turbine at variable wind velocity values with and without the proposed wind tunnel attachment. Statistical analysis of the experimental results demonstrated 60% more power generated using the wind tunnel attachment when compared with the results without the attachment. The results of this study can be used to design similar devices that can be used upstream of a wind turbine to improve performance.

INTRODUCTION

Decline of the fossil fuel reserves and rising energy demand due to increasing population have necessitated the need for more research and development of alternative energy devices such as wind turbine. The current low level of efficiencies of wind turbine has limited the use of wind turbine as they are not yet economically feasible for certain applications. Recently there has been a rise in wind farms throughout the world that help harvest the natural, renewable energy of wind. However, many turbines do not always operate at their maximum efficiency. This could be due to a multitude of factors. This study intends to offer a solution to one of those many factors: low-wind speed.

A number of investigations are being conducted to improve performance of wind turbines using different methods. One of the studies showed that shrouding a wind turbine can increase the power output by more than 60% [1-4]. A wind tunnel apparatus (WTA) is a shrouding that is placed in front of the wind turbine [4]. The inlet of the WTA is larger in diameter than the outlet and is based upon the equation of continuity where the product of the wind velocity at the inlet (v_1) and the cross-sectional area at the inlet (A_1) is equal to the product of the wind velocity at the outlet (v_2) and the cross-sectional area at the outlet (A_2):

$$v_1 A_1 = v_2 A_2 \qquad [1]$$

Equation 1 shows that as the area decreases the velocity of the air is forced to increase. Additionally, the increase of the air velocity causes the wind turbine to generate a higher power output because the power output (P) of a wind turbine is proportional to the swept area of the rotors (A) and the wind speed (v) cubed:

$$P = {}^{1}/{}_{2}\rho A v^3 \qquad [2]$$

Because of high-energy costs today, and concerns about global warming and the effects of air pollution, there has been an increased interest towards renewable energy sources [3]. Although the United States has a vast supply of coal, with almost 30% of world reserves [4], they can produce harmful sulfur dioxide resulting in the production of acid rain and other health hazards. 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. Today, U.S. wind energy installations produce enough electricity on a typical day to power the equivalent of more than 9.7 million homes [5].

The goal of this research is to develop and evaluate a custom constructed wind tunnel attachment for an experimental small scale wind turbine with 400W power rating in the natural environment and inside a controlled laboratory. A cone shaped wing guide apparatus (WGA) is constructed to force air away from the wind turbine hub toward the tips of the wind turbine blades. Air sent to the center of the turbine does not cause the wind turbine to rotate thus producing no usable power. The wind velocities at the inlet and the wind speeds at the outlet were measured with the custom constructed WTA. Additionally, power output of the wind turbine was measured with and without the custom constructed WTA in equal wind speeds to ensure accuracy.

Figure 1 shows a cross sectional of the custom-constructed WTA used in this study. The cone-shaped modification is positioned far back into the WTA to minimize any change in wind direction inside the WTA. The wind turbine is placed directly at the end of the custom-constructed WTA.

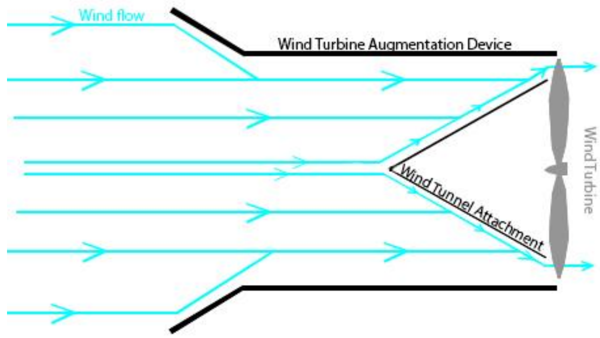

Fig. 1: Cross sectional of Wind Tunnel Attachment (WTA).

The overall length of the WTA is 2 meters long with 1.646 meters inlet diameter and 1.143 meters outlet diameter. The cone-shaped section was designed with 0.75 diameter at the base of the cone. The turbine diameter of the turbine blades used in this study was 1.15 meters as seen in Figure 2.

Fig. 2: Photograph of the WTA.

Methodology

The project involves testing and analyzing a proposed wind turbine attachment to evaluate the performance of an experimental wind turbine at different wind velocities. This includes the development of a custom constructed wind tunnel attachment. An anemometer was used to measure the wind velocities and the power was measured using a multimeter.

The study included the design of a performance improvement device (WTA) by using a diffuser to the experimental small-scale horizontal axis wind turbine and to examine the effects the system on output power generation. Experiments were conducted both in the laboratory and in the field to validate the results. The results of the experiment and the obtained field test data were analyzed using SPSS® 20 software. A 45-inch diameter industrial fan was used to generate artificial wind speed.

Pretest and Post-test experiments were conducted for the experimental wind turbine with and without the use of wind tunnel attachment. Thirty six (36) different tests were performed with the WTA and 36 without the WTA. The collected data was recorded and analyzed in IBM's SPSS version 20 statistical package.

Experiment and Analyses

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. 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 study objective that there is a significant difference between the average means of wind velocities when the wind tunnel attachment was used. See Tables 1&2. Windspeed categories 1 and 2 represent bare wind turbine (when wind hits directly to the blades with no wind augmentation device involved) and WTA (wind augmentation device with cone shaped wind guide attachment) respectively.

Table 1: Descriptive statistics with and without the WTA

Group Statistics

	category	N	Mean	Std. Deviation	Std. Error Mean
windspeed	1.00	36	3.2861	.33308	.05551
	2.00	36	4.2972	.36054	.06009

Table 2: t-Test statistics with and without the WTA

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
windspeed	Equal variances assumed	.325	.570	-12.359	70	.000	-1.01111	.08181	-1.17427	-.84795
	Equal variances not assumed			-12.359	69.565	.000	-1.01111	.08181	-1.17429	-.84793

The t-Test yields the mean of the Category 1 approximately as Mean=3.28 m/s while the mean of Category 2 resulted in approximately Mean 2=4.29 m/s. The p-value obtained from the analysis was p=0.000. less than the alpha level of 0.05, which indicates that there is significant difference between the average means of the wind velocities with the use of custom constructed WTA with the cone shaped wind guide attachment and a bare wind turbine. Individual wind velocities can be better visualized in Figure 4. The authors observed that a higher wind speed at the bare wind turbine generates a larger increase in wind velocity when the WTA is involved. Similarly, as the wind speed decreases the wind velocity also decreases (lower than the bare wind turbine) due to the friction within the WTA system.

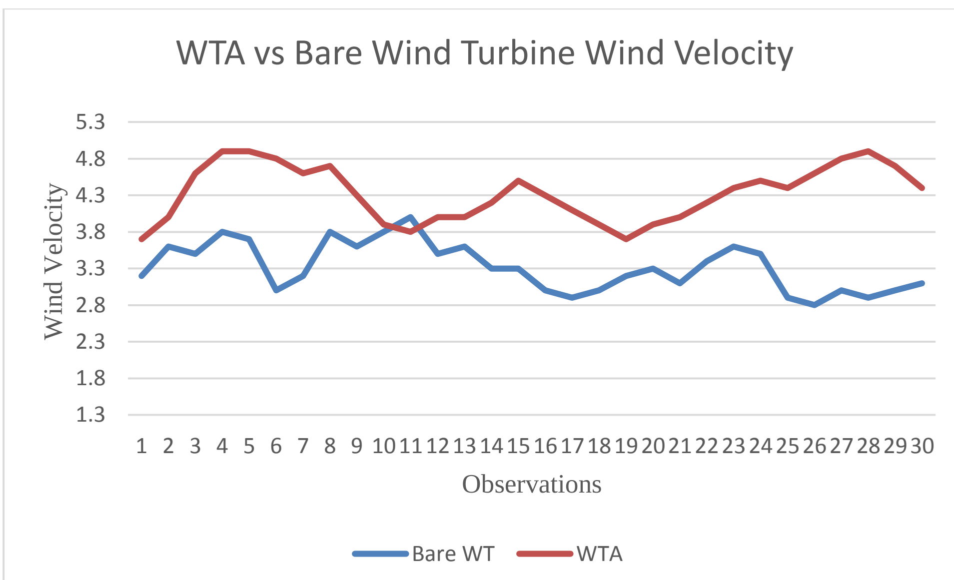

Fig. 4: Wind Velocity Change

One-way analysis of variance was conducted to examine the effect of the WTA on differences in wind velocity changes for statistical significance. Additional wind velocity data was collected for the wind tunnel attachment. This time no wind guide apparatus was mounted to the WTA. The independent t-Test analysis resulted that there is significant difference in the wind velocity change when the cone shaped wind guide attachment was introduced to compare with the bare Wind Turbine.

Tables 3 and 4 show the one way ANOVA test results for the wind velocity output without wind guide attachment system referred as number “3” wind velocity output with cone shaped WGA referred as number “2” and the wind speed output with bare wind turbine referred as number “1”.

Table 3: Descriptive statistics.

Descriptives

windspeed

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1	36	3.2861	.33308	.05551	3.1734	3.3988	2.80	4.00
2	36	4.2972	.36054	.06009	4.1752	4.4192	3.70	4.90
3	36	2.9444	.79082	.13180	2.6769	3.2120	2.00	4.00
Total	108	3.5093	.78509	.07555	3.3595	3.6590	2.00	4.90

In previous studies attachment of a custom designed wind augmentation devices indicated that the wind velocity ouptut increased [1]. However, based on the environmental conditions and the design of the WTA, the wind velocity mean decreased from 3.28 to 2.94. The anova table below shows that there is still a significant difference between the wind velocity means.

Table 4: One way ANOVA

ANOVA

windspeed

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	35.629	2	17.815	61.689	.000
Within Groups	30.322	105	.289		
Total	65.951	107			

One way ANOVA table above for N=36 in each category (Table 3) shows that there is significant difference between the wind velocity changes when custom constructed wind guide attachment is introduced. There was significant interaction between the wind guide attachment, bare wind turbine, the WTA with no WGA mounted and the wind velocity output.

CONCLUSION

An investigation was conducted to evaluate the relationship between wind velocity outputs using a custom-designed wind tunnel apparatus (WTA) with wind guide attachment. Based on the statistical analyses the results showed that there is significant difference in wind velocity means with the application of custom constructed wind tunnel attachment and wind guide apparatus is mounted to the WTA. 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.

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