COMPARATIVE STUDY IN THE OPTIMAL DESIGN OF CUSTOM-CONSTRUCTED WIND AUGMENTATION SHROUDS

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Abstract

In this study, the authors evaluated the impact of wind velocities on power generation, and how wind energy depends on various flow behaviors subject to the medium through which the wind flows. The last two decades have seen rapid growth and improvement in using wind energy to produce electricity, due to concerns relating to global warming and the continuous increase in the price of fossil fuels [1]. Wind power produced increments by a variable of eight when the wind pace was multiplied, which demonstrated that energy available in the wind directly reflects its power [2]. The measure of producible wind is given by $p = 0.5\rho A V^3$, which demonstrates that wind power is largely impacted by speed, specifically the solid shape of wind speed. Previous studies have successfully revealed that, for constant wind available, the shroud with an inlet angle of 30º delivers maximum energy among three different shrouds with inlet angles of 20º, 25º, and 30º [3]. To extend previous research, the authors of this current study tested three distinct covers with differing delta edges of 20º, 30º, and 35º, using IBM SPSS Statistics 22. The goal was to determine the ideal configuration of the cover producing the most wind energy. Results indicated that, for constant wind, the shroud (cover) with an inlet angle of 35º delivered the maximum wind energy among the three different shrouds with inlet angles of 20º, 30º, and 35º. Therefore, this shroud represented the optimal design for achieving maximum wind energy.

Introduction

Wind is one of the consistent and accessible energy sources. The world is experiencing an excessive demand for energy, due to rapid economic growth and industrialization [4]. There has been a huge increase in the consumption of fossil fuels to produce energy. The global carbon dioxide content has grown from 280 ppm in the pre-industrial era to 400 ppm in May of 2013, a 39% increase in carbon dioxide emissions. Recent reports released by the National Oceanic and Atmospheric Administration (NOAA) [5] indicate that global CO_2 content was 399.29 ppm in January of 2015, and had increased to 402.59 ppm by January of 2016. Considering the negative effects of fossil fuels emitting CO_2 and harmful gasses, the continuous increase in the price of fossil fuels, and heavy consumption leading to depletion of resources for future generations, most parts of the world have shown a keen interest in wind energy technologies to produce power [6].

The wind and its abundant nature are attractive as a viable source for electricity generation [7]. The power output a wind turbine can deliver depends on wind velocity, which is responsible for rotating the blades that convert mechanical energy into electrical energy. In this study, the authors explored the effects of wind velocity on the newly augmented shroud devices with varying inlet angles of 20º, 30º, and 35º, designed to maximize wind velocities.

Literature review

Global warming is one of the major threats to the world that everyone should be aware of; we all should act responsibly to control and reduce its future effects. About 80% of global warming results from CO_2 emissions from fossil fuels [8]. Wind power has the ability to stop this potential environmental disaster, as it is pollution free and consumes virtually no water to generate electricity, thus reducing CO_2 emissions [9]. Recent reports indicate an expansion in worldwide wind power limits of 318 GW from 39 GW between 2003 and 2013. On May 11, 2014, at around 1:00 pm, Germany recorded 21.3 GW of wind power capacity, outpacing solar power, which was 15.2 GW. The increase indicates that wind power has the capability of being one of the best resources for generating electricity [10].

The wind turbine is utilized as the main source of transforming wind energy into electrical energy [11]. Wind turbines are usually categorized as horizontal or vertical axis, based on design, and as offshore or onshore, based on the installed location. Power capacity of a wind turbine generally depends on design and wind speed [12]. One major drawback of wind turbine technology is with low wind speeds possessing less energy density per volume of air hitting turbine blades, which increases production costs compared to fossil fuels [13]. Various studies conducted to improve the energy density of wind have shown that concentrator augmented wind turbines would be one of the best ways to improve power capacity and make it more cost effective [14]. To enhance the power capacity of a wind turbine, the authors of this current study have developed three distinct shrouds with inlet angles of 20º, 30º, and 35º, and used in such a way as to enhance the wind speed, which eventually builds the wind power capacity of a turbine.

Methodology

To develop a new technique to improve the power efficiency of a wind turbine, the authors of this study designed and 3D printed three different shrouds with inlet angles of 20º, 30º, and 35º for the tests. The dimensions of the shrouds were designed to produce maximum wind output from the available wind and achieve optimal design. This project involved three different tools: PTC Creo3.0 for designing, Cube Pro for 3D printing, and IBM SPSS for data analysis. Figure 1 shows three 3D printed shrouds attached to cylindrically shaped sheet metal.

Figure 1. 3D-Printed Shrouds

To generate the wind required for the experiment, a 7-inch-diameter blower was used, and the experiment was conducted in a closed environment to avoid any fluctuations in wind direction and velocity. Figure 2 shows the 35° shroud being measured for wind velocity. Using anemometers, 30 different readings of wind velocities were collected at both the inlet and outlet.

Figure 2. Shroud with 35° Inlet Angle

The authors repeated the procedure and collected data from the 20° and 30° shrouds. They then performed a statistical analysis, using one-way ANOVA, to examine the collected data and determine any significant differences between the shrouds.

Data Analysis

A one-way ANOVA test in SPSS Statistics 22 was performed to analyze and compare the differences between the inlet and output velocities of different shrouds. Table 1 presents the descriptive data of the shroud velocities. The mean value column shows that the mean velocity for constant inlet (μ=22.227) was higher for the shroud with an inlet angle of 35° (N=30, μ=28.211), when compared with the other shrouds with inlet angles of 20° (N=30, μ=25.751) and 30° (N=30, μ=25.816). This signifies that the 35° shroud achieved higher efficiency in producing greater output velocity from available constant inlet velocity.

Table 2 presents the ANOVA test data. The p-value was 0.00(<0.05), indicating a significant difference between the output velocities produced by the three custom-constructed shrouds for the constant input velocity.

The Tukey test data in Table 3 reveal a maximum mean difference value (M.D = 5.983) between the inlet and output velocities for the 35° shroud. The statistics show that this shroud has the ability to achieve maximum efficiency to produce greater output velocity from a constant input velocity, when compared with the 20° and 30° shrouds (see again Tables 1 and 2).

Table 1. Descriptive Statistics: Incoming versus Outgoing Wind Velocity

Velocity Type	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	Minimum	Maximum	
					Lower Bound	Upper Bound		
Inlet velocity	30	22.23	1.91	0.35	21.52	22.94	17.77	27.42
20° Outlet Velocity	30	25.75	1.87	0.34	25.05	26.45	21.87	30.82
30° Outlet Velocity	30	25.82	1.91	0.35	25.10	26.53	22.30	33.37
35° Outlet Velocity	30	28.21	3.62	0.66	26.86	29.56	23.36	40.59
Total	120	25.50	3.23	0.29	24.92	26.08	17.77	40.59

Table 2. SPSS ANOVA Output: Inlet versus Outlet Wind Velocity

Velocity Type	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	546.6	3.0	182.2	30.5	0.0
Within Groups	692.3	116.0	6.0		
Total	1238.9	119.0			

Table 3. Post Hoc Test

	Dependent variable	Velocity Type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	Inlet velocity	20° Outlet Velocity	-3.52400*	.631	.00	-5.17	-1.88
		30° Outlet Velocity	-3.58867*	.631	.00	-5.23	-1.94
		35° Outlet Velocity	-5.98333*	.631	.00	-7.63	-4.34
	20° Outlet Velocity	Inlet velocity	3.52400*	.631	.00	1.88	5.17
		30° Outlet Velocity	-.06467	.631	.00	-1.71	1.58
		35° Outlet Velocity	-2.45933*	.631	.00	-4.10	-0.82
	30° Outlet Velocity	Inlet velocity	3.58867*	.631	.00	1.94	5.23
		20° Outlet Velocity	.06467	.631	.00	-1.58	1.71
		35° Outlet Velocity	-2.39467*	.631	.00	-4.04	-0.75
	35° Outlet Velocity	Inlet velocity	5.98333*	.631	.00	4.34	7.63
		20° Outlet Velocity	2.45933*	.631	.00	0.82	4.10
		30° Outlet Velocity	2.39467*	.631	.00	0.75	4.04

Conclusion

The motivation behind this study was to examine the ideal design for uniquely built wind augmentation devices. The authors developed three designs with various inlet angles of 20°, 30°, and 35° for comparing wind flow efficiency. The one-way ANOVA test results showed that the 35° shroud amplified wind velocity significantly, compared to the inlet wind velocity of the shroud. Moreover, this shroud was the most efficient with the highest mean values of wind speeds at the exit. In terms of efficiency of velocities at the exit, the 35° shroud followed the 30° and 20° shrouds.

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