Comparative Study of Various Custom-Constructed Wind Augmentation Shrouds for Optimal Design

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Abstract

This study represents the impact of wind velocities on the power generation and how the wind energy is dependent on the various flow behaviors of the wind subjected to the medium it is allowed to flow through it. A rapid growth and improvement in the utilization of wind energy to produce electricity is observed in the last two decades because of the concerns relating to global warming and continuous increase in the prices of fossil fuels [1]. Wind power produced increments by a variable of eight when the wind speed is multiplied which demonstrates that energy available in the wind directly reflects the wind power [2]. The wind power is calculated using the equation $P = 0.5\rho A V^3$. The equation demonstrates that the wind power is largely impacted by the wind speed, as it is proportional to the wind velocity. Previous studies have successfully revealed that for constant wind available the shroud with inlet angle 30 degrees has been delivering the maximum wind energy among three different shrouds of inlet angles 20, 25 and 30 degrees [3]. This study focuses on the shrouds with inlet angles of 20, 30 and 35 degrees and the best optimal design shroud is reported using IBM SPSS statistics 22 software. The statistical analyses performed on the data collected from this experiment have successfully showed that for constant wind available the shroud with inlet angle 35 degrees has been delivering the maximum wind energy. The result of the analysis projected that the shroud with inlet angle 35 degrees is the best optimal design for the shroud to achieve maximum wind energy among the three shrouds.

Introduction

The wind is one of the continuously occurring and naturally available source of energy production to the mankind. The world is experiencing excessive demand for energy due to the rapid economic growth and industrialization [4]. There is a huge increase in the consumption of fossil fuel to produce energy. The global Carbon dioxide content in the environment has up scaled from 280 ppm in the pre-industrialization era to 400 ppm in May 2013.This report shows a 39 percent increase in the Carbon dioxide emissions to the environment. Recent reports submitted by National Oceanic and atmospheric administration (NOAA) on March 7, 2016 states that the global CO_2 content in the environment was 399.29 ppm in January 2015, which increased to 402.59 ppm in January 2016[5]. The negative effects of the fossil fuels emitting CO_2 and harmful toxic gasses, continuous increase in the prices 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].

Impressive characteristics of the wind and its abundant nature are attracting the world to see wind energy as the best means of the source to generate electricity [7]. The power output a wind turbine can deliver highly depends on the wind velocity. The wind velocity is responsible for rotating the blades in order to convert the mechanical energy into electrical energy. The purpose of this study is to explore the newly augmented shroud devices with varying inlet angles of 20, 30 and 35 degrees designed to optimize wind velocity. Furthermore, the wind velocity is diverted to the wind turbines to generate maximum power. The authors of this study, one from Civil Engineering background and the other from mechanical engineering were provided with the ability to perform statistical analysis, learn 3D modeling, as well as 3D printing technology.

Literature review

Global warming is one of the major threats to the world, which everyone should be aware of and act responsibly in controlling and reducing its future causes. About 80% of the global warming is caused due to the CO_2 emission from the fossil fuels [8]. Wind power has the ability to stop this environmental disaster, as it is pollution free and consume nearly zero percent of water in generating electricity thus reducing CO_2 emissions [9]. Recent reports have demonstrated an expansion in the worldwide wind power capacity to 318 GW from 39 GW between 2003 and 2013[10]. On May 11th, 2014 around 1 pm, Germany recorded 21.3 GW of wind power capacity leaving behind solar power, which was 15.2 GW indicating that wind power has the capability of being one of the best resources to generate electricity [10]. The wind turbine is utilized as the main source to transform wind energy into electrical energy [11]. Wind turbines are usually categorized as the horizontal axis and vertical axis based on design, and into an offshore wind turbine and onshore wind turbine based on the installed location. Power capacity of a wind turbine generally depends on its design and the 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 increase the production cost compared to the fossil fuels [13]. Various researches conducted to improve the energy density of wind have shown that Concentrator Augmented Wind turbines (CWTs) would be one of the best ways to improve power capacity and make it cost effective resource [14]. To enhance the power capacity of a wind turbine the researchers of this study composed and investigated three distinct shrouds with inlet angle of 20, 30, and 35 degrees respectively. These shrouds are designed to allow maximum airflow towards the blades, which enhances the power generating capacity of wind turbine.

Methodology:

To develop a new technique to improve the power efficiency of a wind turbine from low wind velocities the authors of this paper have designed and 3D printed three different shrouds with inlet angles 20, 30 and 35 degrees to perform the analysis. The dimensions of the shrouds were designed such that they could produce maximum wind output from the available wind and achieve the best optimal design. This project involved three different tools such as 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 shape sheet metal.

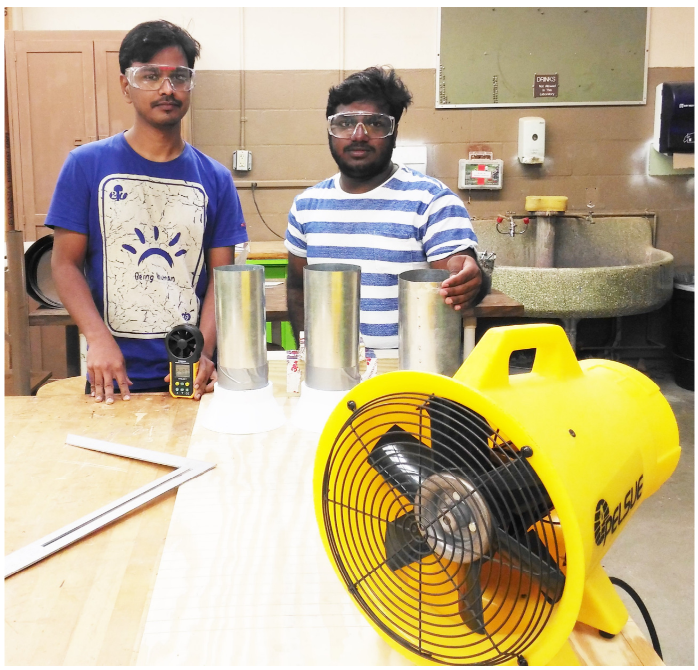

Figure 1: 3D printed shrouds

To generate the wind required for the experiment a blower of 7-inch diameter was used and the experiment was conducted in a closed environment to avoid any fluctuations in the wind direction and its velocity. Figure 2 shows three shrouds with 20°, 30° and 35° inlet angle and the blower which is used to generate the wind. Using the anemometers 30 different readings of wind velocities was collected both at inlet and at outlet of the shroud.

Figure 2: Shroud with 35-degree inlet angle

The authors repeated the procedure and data are collected from 20° and 30° shrouds. A statistical analysis is performed using One-way ANOVA to analyze the collected data to determine if there are any significance differences between the shrouds.

Data Analysis

One-way ANOVA test in the IBM SPSS statistics 22 was performed on the data recorded during the experiment to analyze and compare the velocity differences between the inlet and output velocities of different shrouds.

Table 1 represents the descriptive data of the velocities of different shrouds. The mean value column of Table 1 shows that the mean velocity for constant inlet mean velocity (μ=22.227) were higher for the shroud with inlet angle 35° (N=30, μ=28.211) when compared with the other shrouds of inlet angles 20° (N=30, μ=25.751) and 30° (N=30, μ=25.816) which signifies that the 35° shroud had achieved higher efficiency in producing greater output velocity from available constant inlet velocity.

Table 1 – Descriptive statistics, Descriptive Statistics, Incoming vs 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 represents the ANOVA test data to determine if there is any significant difference between the output velocities of different shrouds. The p-value is 0.00(<0.05) which projects that there is a significant difference between the output velocities produced by the three custom constructed shrouds for the constant input velocity.

Table 2 – SPSS ANOVA Output, Inlet vs 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			

Tukey test in Table 3 reveals that there is maximum mean difference value (M.D = 5.983) between the inlet and output velocities for the shroud with 35° inlet angle. Tukey test and descriptive show that the 35° inlet angle has the ability to achieve maximum efficiency to produce greater output velocity from constant input velocity when compared with 20° and 30° shrouds (Tables 1 and 2).

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 optimal design for custom-built wind augmentation devices. The authors developed three designs with various inlet angles 20°, 30° and 35° respectively for comparing wind flow efficiency. One-way ANOVA test resulted that the 35^0 angled shroud amplified wind velocity significantly compared to the inlet wind velocity of the shroud. Moreover, the 35^0 shroud was the most efficient with the highest mean values of wind speeds at the exit of the shroud. In terms of efficiency of velocities at the exit of the shroud, 35° shroud was followed by 30° and 20° respectively.

References

[1] Ming-Shun Lu; Chung-Liang Chang; Wei-Jen Lee; Li Wang. Industry applications society IEEE-IAS 2008 annual meeting (2008). *IEEE Industry Applications Magazine*, *14*(3), 11–11. doi:10.1109/mias.2008.918515

[2] Dakeev, U. (2016). Comparative Study of custom-constructed Wind Augmentation Shrouds on a small-scale Wind Turbine. American Society for Engineering Education.

[3] Iowa Energy Center- Wind Speed and power. (2016). Retrieved March 3, 2016, from Iowa energy center, http://www.iowaenergycenter.org/wind-energy-manual/wind-and-wind-power/wind-speed-and-power/

[4] Leung, D. Y. C., Caramanna, G., & Maroto-Valer, M. M. (2014). An overview of current status of carbon dioxide capture and storage technologies. *Renewable and Sustainable Energy Reviews*,*39*, 426–443. doi:10.1016/j.rser.2014.07.093

[5] ESRL global monitoring division - global greenhouse gas reference network. (2005, October 1). Retrieved March 3, 2016, from http://www.esrl.noaa.gov/gmd/ccgg/trends

[6] Xu, J., Li, L., & Zheng, B. (2016). Wind energy generation technological paradigm diffusion.*Renewable and Sustainable Energy Reviews*, *59*, 436–449. doi:10.1016/j.rser.2015.12.271

[7] Research paper. (2009). Retrieved March 3, 2016, from http://www2.hawaii.edu/~dsnellin/100/Researchpaper.html

[8] Afnan ,M; Tahani, H; Eman,A. (2016) Global warming awareness among the University of Bahrain science students, doi: 10.1016/j.jaubas.2016.02.002

[9] Global Wind Energy Council (GWEC), Global Statistics (2014) last accessed January 15, 2015, http://www.gwec.net/global-figures/graphs

[10] Morris, C. (2014, May 13). *German power prices negative over weekend*. Retrieved March 1, 2016, from http://energytransition.de/2014/05/german-power-prices-negative-over-weekend/

[11] Wenyi ,L. (2016) Design and kinetic analysis of wind turbine blade-hub-tower coupled system, doi: 10.1016/j.renene.2016.03.068.

[12] Ojosu, J.O. & Salawu, R.I .(1989) An evaluation of wind energy potential as a power generation source in Nigeria, doi:10.1016/0741-983X(90)90041-Y

[13] Phillips, D.G.(2003) An investigation on diffuser augmented wind turbine design (Ph.D. thesis), The University of Auckland, http://hdl.handle.net/2292/1940

[14] Chipo, S & Golden, M. (2016) Concentrator Augmented Wind Turbines: A review, doi: 10.1016/j.rser.2016.01.067

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