Analysis of a Custom Constructed Wind Augmentation Device with 30 Degree Inlet Section to Improve Wind Power Generation

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Abstract

The purpose of this research is to build and test a wind augmentation device that might improve power generation of an experimental small scale wind turbine. Testing of the wind turbine with shroud is conducted to justify the means of adding a shroud around a wind turbine to increase the speed of airflow thus generating more energy from the wind turbine. Researchers developed a wind turbine system with shroud through which the power efficacy can be improved and a cone to allow the incoming airflow from the wind turbine for a greater output. Previous research revealed that a shroud with 30 degree angle connected to the wind turbine can deliver significantly improved performance and power efficiency when compared to other shrouded wind augmentation devices with different angles [1]. For this study the authors constructed a large wind augmentation device in which the angle of the inlet remains 30 degrees. The device measures 100 inches in length and 50 inches outlet diameter. A cone of 20 inches height and 10 inches diameter is inserted into the shroud. The performance of the shrouded wind turbine is experimentally and numerically investigated at various wind speeds as well as power output. Furthermore, the power output parameter was compared between shrouded wind turbine with a cone and a shrouded wind turbine without a cone. The shrouded wind turbine with a cone has demonstrated power augmentation by a factor of about 65% compared with a wind turbine without cone, for a given turbine diameter and wind speed.

Introduction

Utilization of wind energy dates back to 3000 years and was initially used to grind grain with drive windmills, to propel ships and to pump water [2]. Conventional energy sources and nonconventional energy sources are the two types of energy sources available for power generation to the world. Because of the continuous price hikes, global warming issues and the limited nature of the conventional energy sources like coal, petroleum, natural gas etc. has made the authors of this paper to suggest that nonconventional energy sources like solar power generation, wind power generation, MHD power generation, fuel cells, thermo-electric generation would be the best option to use as a source of power generation in future [3].
From 3.5GW in 1994 to approximately 320GW of wind power production capacity by the end of 2013 projects that there has been a tremendous improvement in the application of wind energy over the last two decades [1]. An important motivating factor for the authors of this paper to use wind energy for power production is a fact that wind energy is a nonpolluting component and environmental friendly technique used in generating power which does not emit carbon dioxide and any other toxic gases compared to fossil fuels or nuclear power generation [4].
It was in 1951 John Brown & co have built the first utility grid connected wind turbine. Wind turbines have been effectively generating power by converting kinetic energy present in the wind to mechanical energy which in turn converts in to electrical energy with the help of a generator. In 2014, in order to encounter problems relating to the power demand with respect to the available current supply, China has installed large scale wind farms of capacity around 114,609 MW wind energy which contributed 31% of the total wind power followed by USA, Germany, Spain and India which produced 65,879 MW, 39,165MW, 22,987 MW, and 22,465 MW wind power respectively [5].

Literature review

Many Endeavors have been made till date in making best use of the natural resources to generate energy and wind energy is one of them [6][7][8]. Though there are many projects which involve power generation using wind energy the main concern is how to increase the throughput of the wind within the tunnel and to concentrate wind on the blades of the turbine. According to Department of Mechanical Engineering-Gurion University of the Negev, the energy production can be improved by increasing wind velocity through the blades of the turbine using shroud attachment in the tunnel[9]. In the present study, the researchers are using a conical shroud in the wind tunnel because a conical member having a substantially constantly increasing diameter in the wind flowing direction. In another embodiment, the conical member smoothly expands in the wind flowing direction.
The efficiency of a conventional wind turbine is limited. Therefore, a wind turbine system that consists of a shroud with a cone was developed to overcome these weaknesses. As stated in 2014 Fifth International Conference on Intelligent Systems [10] the shroud with a cone has the role of collecting and accelerating the approaching wind, thus improving the efficiency of the wind turbine. In the numerical simulation, it was found that the shroud could accelerate the approaching wind speed by a factor of 2.1 and augment the power output of a wind turbine by 3 times [10]. However, in the shrouded wind turbine experiment, a velocity enhancement of 1.33 times was achieved and a power output augmentation of 2 times was

demonstrated [10]. A collection-acceleration device was developed for wind, which was a diffuser shroud equipped with brim, called wind – lens. The researchers tested two types of hollow-structure models; a nozzle, and a diffuser type. Their experiments revealed that the diffuser-shaped structure could accelerate the wind at the inlet [12] . Another research reported that the power generated by an experimental small-scale wind turbine increased more than 60% when the shroud was introduced. The researchers tested and analyzed the wind shrouding to evaluate the performance of the wind turbine at various wind velocities. The conclusion is given that power generation significantly increased with the wind shrouding system [13] [14] . The researchers tested and analyzed the performance of wind shrouding with 20, 25 and 30 degree angles respectively at various wind velocities and determined that the shroud with a 30 degree angles exhibited maximum performance at various wind velocities [11]

Methodology

The authors of this paper have modeled and 3D printed three different custom constructed shrouds with inlet angle 20,25,30. The shroud with 30 degree angle was selected as it deliver significantly improved performance and power efficiency when compared to other shrouded wind augmentation devices with different angles and a large wind augmentation device was manufactured using galvanized steel as shown in Figure1. The device measures 60 inches in length, 50 inches outlet diameter and 72 inches inlet diameter.

Figure 1 – Wind Augmentation Device

A cone of 20 inches height and 10 inches diameter is inserted into the shroud as shown in Figure2. The cone was shaped and constructed to allow the incoming air flow for greater output.

Figure 2 – Wind Augmentation Device With Cone

Two optimal locations generated high wind flow at XXX University, parking lot to conduct the experiment. The inlet and outlet wind velocities are collected using two anemometers at inlet and outlet as shown in Figure 3 for data collection.

Figure 3 – Wind Data Collection

A total of 72 readings 36 for each inlet and outlet wind velocities are recorded at two different locations . The theoretical power values are calculated using the formula $p = \frac{1}{2}\rho a v^3$ utilizing the input and output velocities recorded individually at two different locations. The obtained power is analysed using a statistical software called IBM SPSS Statistics. In SPSS, t-test analysis is performed to compare the power input and power output,if there exists any significant difference between them.

Data Analysis:

The authors of this paper used IBM SPSS statistics 22 software to conduct the statistical analysis on the data collected at two different locations. T- test was utilized to compare the means between the input power and output power at each location individually and determine if there exists any significant difference between the input power and output power.

Location 1

Table 1 represents the descriptive statistics of the t-test analysis. The mean column in the Table 1 shows that the mean value for the out power (N=36,μ=7.7225)was higher when compared to the input power mean(N= 36, μ=3.0222), which signifies that the authors of this research could successfully utilize the custom constructed shroud to improve the power output from the available input wind.

Table 1 –Descriptive Statistics

Datapoint		N	Mean	Std. Deviation	Std. Error Mean
Power	Inlet power	36	3.02	2.16	0.36
	Outlet power	36	7.72	5.59	0.93

Table 2 represents the Independent sample t-test of the analysis. Table 2 shows that according to Levene's Test the data collected possess unequal variances as the p-value is 0.002 (<0.05) and also there exists significant differences between output and input power as two tailed p-value in the table 2 is 0.000(<0.05). From the t-test analysis the authors of this paper were successful in increasing the power efficiency of the wind from the available wind at Location1.

Table 2 – t-Test For Equality of Means

		Levene's Test		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Power	Equal variances assumed	10.74	0.00	-4.71	70.00	0.00	-4.70	1.00	-6.69	-2.71
	Equal variances not assumed			-4.71	45.22	0.00	-4.70	1.00	-6.71	-2.69

Location 2

The descriptive statistics for location 2 is represented by Table 3. The mean section in the table 3 reveals that the mean value for the inlet power and outlet power. Outlet power mean value (N=36,μ=8.5463) is higher when compared to the inlet power mean value (N= 36, μ=4.8514), which signifies that the power output can be amplified by the utilization of 30° constum constructed shroud.

Table 3 – Statistical Analysis

Datapoint		N	Mean	Std. Deviation	Std. Error Mean
Power	Inlet power	36	4.48	4.85	0.81
	Outlet power	36	8.55	10.40	1.73

The Independent sample t-Test for the readings recorded at location 2 is represented by Table 4. The data collected at location 2 has unequal variances acoording to the Levene's test which states that the data possessing unequal variance ($p<0.05$) violate homogeneity of variances. The two tailed sig. (p-value) in the Table 4 reveals that there exists significant differences between output and input power as p-value is 0.037(<0.05). The t-test for equality of means data results signifies that there is a significant difference between the wind power at inlet and outlet sections of the shroud recorded at location 2.

Table 4 – t-Test For Equality of Means

		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
Power	Equal variances assumed	4.68	0.03	-2.12	70.00	0.04	-4.06	1.91	-7.88	-0.25
	Equal variances not assumed			-2.12	49.55	0.04	-4.06	1.91	-7.90	-0.22

The researchers of this paper used the Primus AIR 40 wind turbine manufactured by Primus Wind Power company as a reference to compare the theoretical efficiency in the power they achieved using the shroud. The technical specifications of the wind turbine provided by the manufacturer included that the wind speed operating range of the turbine to be between 3.1 - 22 m/s. Beltz's law states that the maximum kinetic energy a wind turbine can utilize is 59.3% from the available wind[15]. One of the data values collected by the authors recorded outlet velocity as 3.37 m/s and the inlet velocity was 2.66 m/s. This shows that the Primus AIR 40 wind turbine if installed within the wind augmentation shroud system designed by the authors can operate at lower cut-in speeds (2.66 m/s) than actually specified by the manufacturer (3.1 m/s).

Conclusion

The purpose of this study was to investigate the optimal design for wind augmentation devices to increase the power output at the outlet. Based on the wind velocity outputs recorded from 3D printed shroud, the authors decided to construct a wind augmentation shroud with galvanized steel of 30° inlet angle to investigate whether there is significant difference between the power at the inlet and outlet of the shroud. The analyzed data shows that there is increase in the power output at the outlet of the shroud. These calculations are based on the 72 wind data points collected at two different locations in xxx university.The calculated power increase confirms that the use of cone to direct the air flow toward the wind turbine yields more power output.Further more, we are working on different sizes and shapes of cone to increase the power efficiency.

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