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Design and Development of a New Small-Scale Wind Turbine Blade

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Design and Development of a New Small-Scale Wind Turbine

To meet the increasing demand for renewable energy, amount of energy harnessed by wind turbine must be increased. The objective of the current study is to design and development of a new blade geometry for small scale wind turbines that will generate more power than the currently available designs. A modified cone shaped, flow directing device was also designed and installed at upstream of the wind turbine to increase the air velocity. Experiments were conducted with and without the above mentioned device to compare the power generated by the turbine. The experimental results demonstrated an increase in power output by 60% when the cone shaped device was used. A new blade was designed and constructed that will be able to utilize the downstream effect of the flow directing device. The new blade design was capable of generating 400 watts of power output when used in conjunction with the flow directing device. The number of blades, location, and surface area of the blades were considered during the design process.

Introduction

Rising energy demand due to technological advancement across the world and decline in fossil fuel production have necessitated the need for more research and development of alternative energy devices such as wind turbine. Small-scale wind turbine efficiencies could benefit societies to become independent renewable energy producers from wind. However, current level of efficiencies of small-scale wind turbines have limited the use of wind turbines as they are not economically feasible. Polar vortex in 2013[1] proved that wind turbines can become cost beneficial during unexpected energy demands. Additionally, rise in wind energy production throughout the United States made USA as the world leader in wind power production [1]. However, many turbines do not always operate at their maximum efficiency. This could be due to a number of factors including the wind turbine blade design. In previous studies researchers were able to increase wind power output by 40-60% [4] by designing a shrouding system that could amplify incoming wind velocity. The Equation below shows that slight change in wind velocity could significantly increase power output from a small-scale wind turbine, all other parameters for wind turbines assumed constant. This study investigates a relationship between a custom-designed small-scale wind turbine blades with the wind augmentation device presented by [3] "*By increasing the parameters of the blades there will be a relative increase in power output*." [6]

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

While most conventional small-scale wind turbines pose a few problems when attached to the wind augmentation system, custom constructed blades may offer more efficient collection of wind. The ambition of current design is to increase the wind power output by eliminating the blade section that is covered by the cone of the wind augmentation apparatus as shown in Figure 1. Therefore first and second year engineering students experienced a hands-on project that challenged their goal: to come up with a design that could improve power output on small-scale wind turbines.

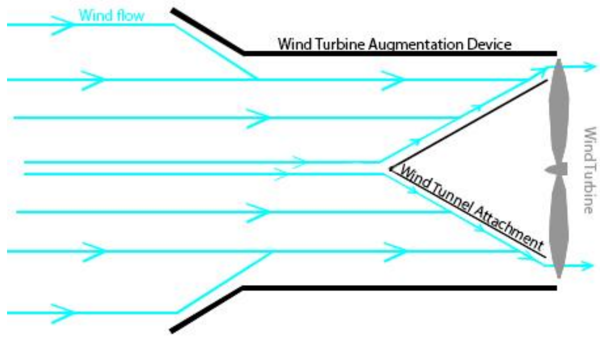

Figure 1. Cross sectional of Wind Tunnel Attachment (WTA). ***(Modified from Dakeev, & Mazumder, 2014)***

National Renewable Energy Laboratory (NREL) reported that today's world is thriving on the idea of renewable energy [7]. Scarcity of nonrenewable resources necessitated increasing demand for energy sources that are naturally occurring and easily replenish. While most countries rely heavily on fossil fuels, these resources are not considered renewable due to the limit in supply. Contrary to this, other means of energy such as wind and solar are constantly being renewed and will never expire [2].

New designs and innovative ideas are driving wind industry forward to better suit the needs of a more urban environment. While the easiest way to increase the power output of a wind turbine is to maximize the diameter of the blades [8], channeling a moving air through a shrouding (Figure 1) with a cone-shaped extrusion to direct the wind toward the tips of the blades increased the power production as well [5].

Methodology

The current study involves design, manufacture and test of a new wind-turbine blade to generate more power with higher efficiency. Freshmen and sophomore students in computer aided design course developed 3D model of the blade and printed in a 3D printer. Dimension 1200es 3D printer can contain 11x11x12 inches in its envelope, therefore the constraints for the students were to come up with a design to fit into the 3D printer's specification. The wind turbine with hub-mounted blade assembly is presented in Figure 2. Freshmen and sophomore students in Mechanical Engineering program disassembled the existing small-scale wind turbine, took the measurements to develop adjustable hub to contain proposed custom-constructed wind turbine blades. The wind turbine design was based on an existing diffuser with cone assembly that was used for testing the wind turbine as shown in Figure 3. This diffuser dimensions are approximately 60 inches in length, 47 inches in the narrowest section and 60 inches in the inlet section. Diffuser and cone dimensions were adapted from [5] wind management paper. The experimental small scale wind turbine was selected to replicate similar results by Dakeev & Mazumder [5]. However, the experimental wind turbine in this study had 1 kW power rating and some assumptions were adopted. Experiments were conducted in the engineering laboratory using an industrial fan, flowing air through the diffuser to the wind turbine. The results were analyzed using SPSS® 22 software to compare the power output from a conventional and the new custom designed blade. The weather channel showed mean air temperature 23ºF during the experiment, with 10 mph mean wind velocity, and mean barometric pressure 30.02[10].The students carried out the experiment in the closed laboratory condition. The experiments were conducted in two phases. In the first phase, conventional small-scale experimental wind turbine was placed behind the diffuser system to replicate Dakeev's [3] study with various wind velocities. The second phase involved generating same wind velocities with the proposed wind turbine blades mounted on the same experimental wind turbine. The engineering students conducted t-Test analysis to compare means of power outputs for two types of wind blade designs (conventional and proposed/custom-constructed). The wind velocity ranged from 2.8 mph to 11.5 mph with average 6.14 mph at the inlet of the wind shrouding device. The average wind velocity at the outlet resulted in 7.32 mph under the same laboratory conditions.

Assumptions

The following assumptions were made by mechanical engineering students while conducting the experiments:

- The guided airflow through the diffuser was same in all cases of experiments
- Atmospheric pressure, air density, and environmental conditions (within the laboratory) remained same throughout experiments
- Manufacturer's specifications for the experimental wind turbine remained same with no power loss with the change of experimental setups
- Developed 3D model of the experimental blade was optimal for 3D printing, and that the 3D printed parts were optimal for this study
- 3D printed hub did not have or had negligible effect on the rotational velocity of the wind turbine

Figure 2. Custom constructed wind turbine blades

Figure 3: Experimental set-up of new wind turbine with flow directing diffuser.

Analysis of Experimental Results

Two different blade designs, conventional and custom constructed, were tested for optimizing the power output and efficiencies. The control variables during the experiment were wind velocity and the proposed blades. A t-test analysis was performed on the difference of the blade designs in relation to the incoming wind velocity to determine if there is a significant difference between power outputs when custom constructed blades are used in the wind augmentation device. Table 1 shows the mean averages for both conventional blades (Mean=189.27) and custom blades (Mean=298.99) with 19 data points in watts.

Table 1: Descriptive Statistics for Wind Turbine Blade Types (Watts)

Group Statistics

Category		N	Mean	Std. Deviation	Std. Error Mean
Power Output	Conventional Blades	19	189.27	214.21	49.14
	Custom Blades	19	298.99	261.25	59.93

Table 2 illustrates the t-Test analysis for power output means for two types of wind turbine blades. The results in table 2 show the p-value (p=.22) greater than the alpha level (alpha level = 0.05) indicating no significant difference between the power outputs when two different types of wind turbine blades were mounted on the experimental wind turbine. This means the power output with the use of custom constructed wind turbine blades did not yield significantly improved power output compared to the conventional blade design under similar wind conditions.

Table 2: t-Test statistics for Wind Turbine Blade Types (Watts)

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
Power Output	Equal variances assumed	1.54	0.22	-1.42	36.00	0.17	-109.72	77.51	-266.91	47.47
	Equal variances not assumed			-1.42	34.67	0.17	-109.72	77.51	-267.12	47.68

Although the statistical analysis did not result in the significant differences in the types of blades used to produce wind power output, Table 1 and Figure 4 below clearly indicate that the custom constructed blades have potential for further investigation. Individual power output data can be better visualized in Figure 4, where nineteen data points for wind power output by the experimental wind turbine were compared. Each data point represents power output for corresponding wind velocity. The wind velocity ranged from 2.8 miles per hour (mph) to 11.2 mph, which is typical average wind range in the area. The authors observed that a higher power output was obtained from the experimental wind turbine when the proposed blades were mounted.

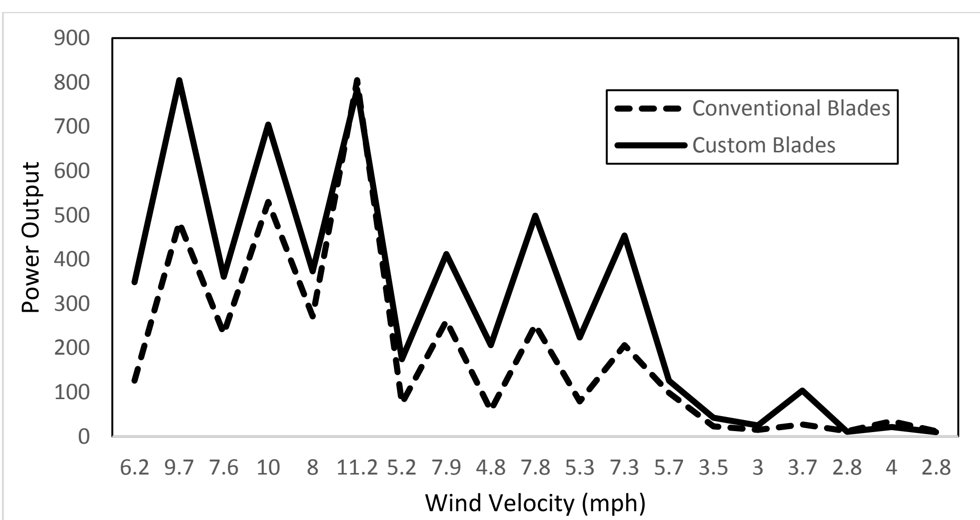

Figure 4. Comparison of Power output from conventional and new blade design (Watts)

Conclusion

An investigation was conducted to evaluate the wind power outputs produced with two different wind turbine blades. Previous studies suggested that power production increases with the introduction of wind augmentation device (Yuji, Takashi, Akira, Keneichi & Masahiro, 2008). This study validated that the power output increases in relation with the wind velocity when both blade types are used. However, the authors did not observe significant difference in the power output means when the blade types were compared at $\alpha = 0.05$ levels. Based on the descriptive statistics and comparative run charts the custom constructed blades have potential when used with the wind augmentation device. This experimental study enabled engineering students to design, model, manufacture, conduct experiments, collect data, analyze the results, and report findings to a large audience.

Recommendations

Further studies need to be considered on the environmental field tests. The artificial fan may have generated turbulence that affected the power output. Additionally, optimization of pitch angles on the custom constructed blades may reveal different results. The cost effectiveness of the current system was not analyzed for a large-scale wind turbines therefore; the custom blade material may be brittle at higher wind gusts.

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