A Comparison of Power Generation for Different Blade Designs for a Horizontal Axis Wind Turbine (HAWT)

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Introduction

With the increasing demand for green energy and the push to move away from fossil fuels, the efficiency of converting energy from a renewable source to a more usable form is becoming more important.

This project seeks to design a system in which various wind turbine models and blade designs can be integrated with a wind tunnel to be tested for the efficiency of their conversion from wind to electrical energy. The efficiency of each blade design is tested experimentally by observing the voltage output for set wind speeds.

By testing a variety of design factors of the blades, it can be determined what the general design requirement should be for the blades of a horizontal axis wind turbine. Additionally, the air flow around each blade was visualized by seeding the air with particles and using a laser.

Methodology

First, the setup for how the wind turbine would be tested was determined . This was set to be done using a tripod with a metal rod projecting from it on which the turbine could be held.

After the setup for the test was determined, it was decided that any mechanical components directly related to the wind turbine would be 3-D printed to allow for quick prototyping. Thus, firstly a part to interface with the tripod setup, generator, and turbine hub was designed.

A hub to which various blade designs could be attached was then designed and printed.

After the hub design was completed, the circumference of the attachment points were measured, and three blades were appropriately designed and printed. One design was based on a cross-section determined by 'Airfoil Tools' and the other two were independently designed cross sections.

Following the printing of the blades, any adjustments needed were done by either sanding the part of the blades which interfaced with the hub or resizing the design and printing the blades again.

To measure the power generated, the turbine was positioned perpendicularly to the wind tunnel and a full-wave rectifier and 10kΩ resistor were attached to the generator.

Following this, the wind speed was varied and the output voltage across the resistor was measured with a Fluke Digital Multimeter. The angle of the blades was adjusted, and these measurements were done once more.

Graphs of DC Voltage against Wind Speed were then plotted and interpreted.

After the necessary experimental values for voltage generated at various wind speeds were collected, the air flow around each blade was visualized both while the blades were still and in motion.

To do this, the air in the wind tunnel was seeded with particles and a laser was projected across one of the blades of the turbine. The motion of the air was captured using a Phantom high-speed camera

Experimental Setup

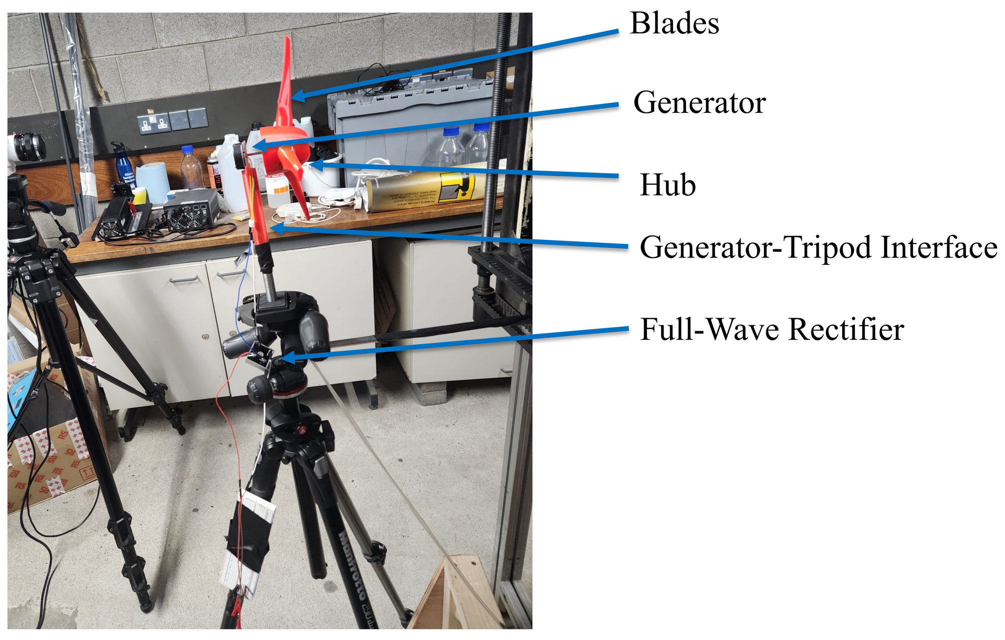

Figure 1. Complete setup of Wind Turbine

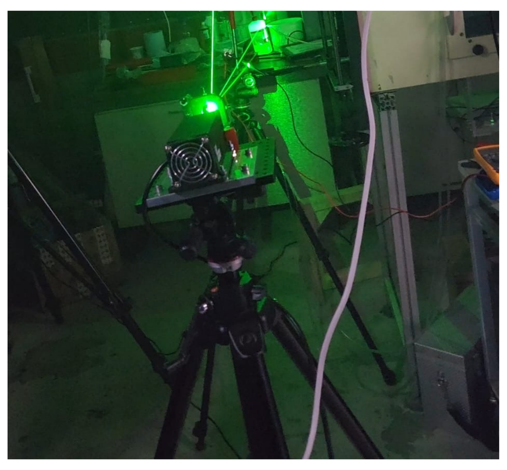

Figure 2. Setup for Flow Visualization

Results

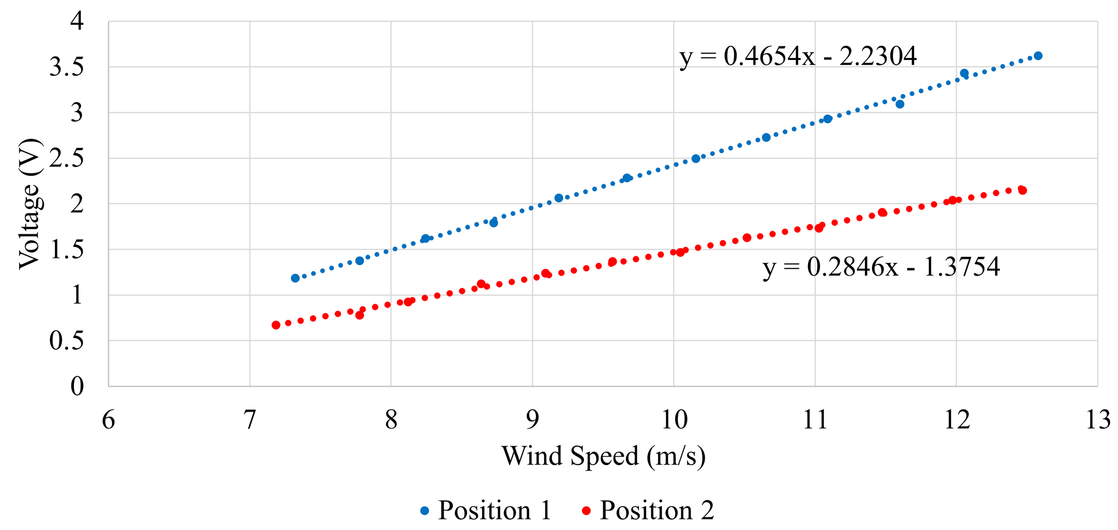

Figure 3. Graph showing Output Voltage at Specified Wind Speeds for Blade Design 1

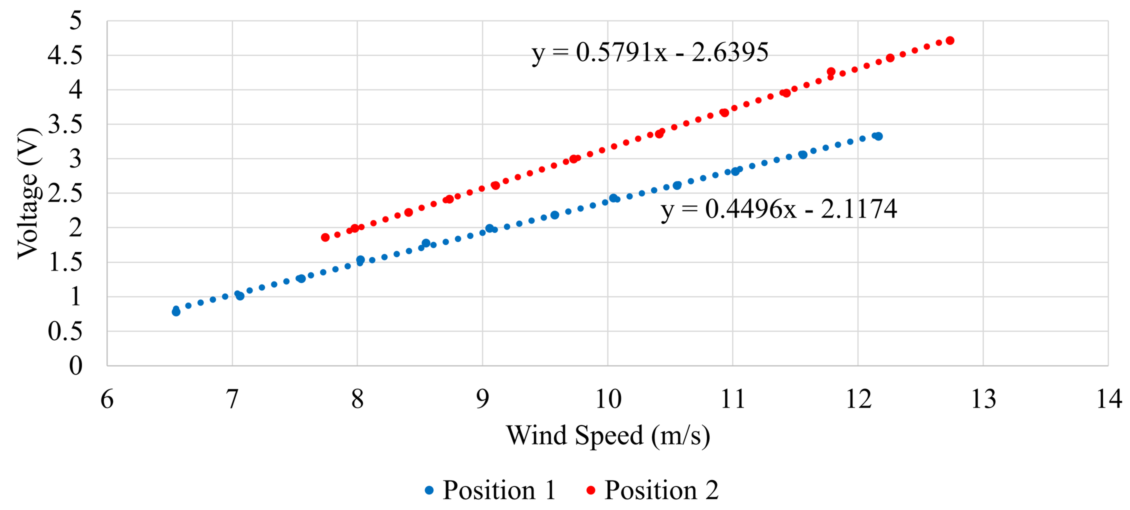

Figure 4. Graph showing Output Voltage at Specified Wind Speeds for Blade Design 2

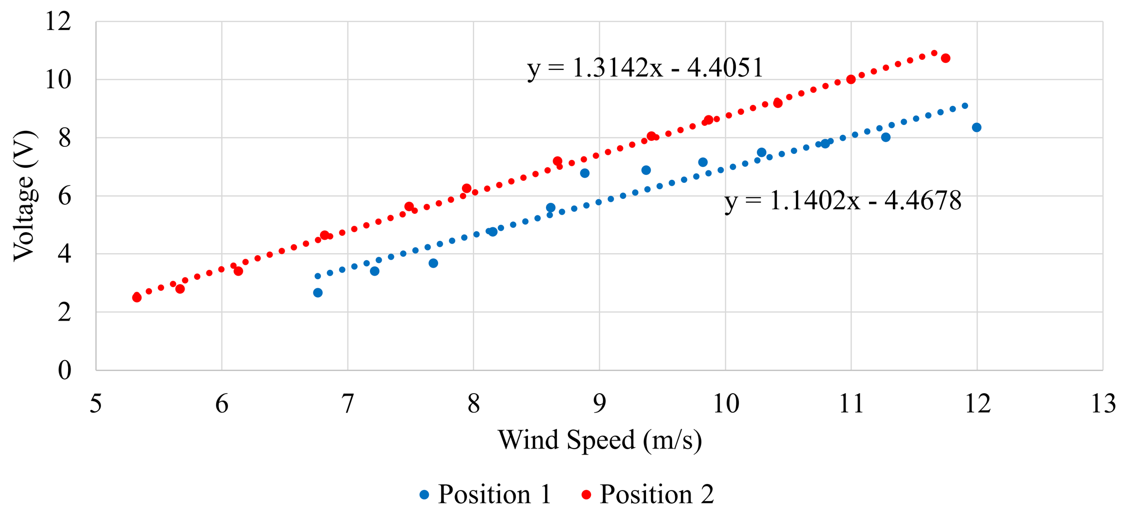

Figure 5. Graph showing Output Voltage at Specified Wind Speeds for Blade Design 3

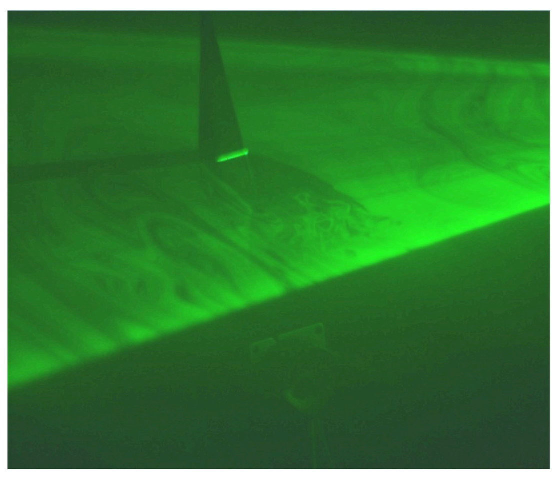

Figure 6. Image of Vortex around Blade 1 when it is still

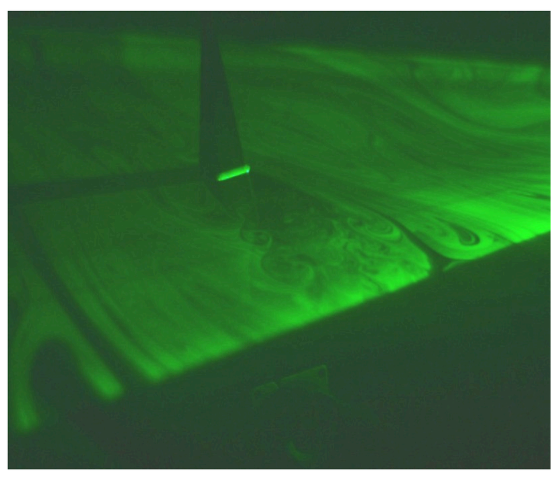

Figure 7. Image of Vortex around Blade 1 when it is in motion

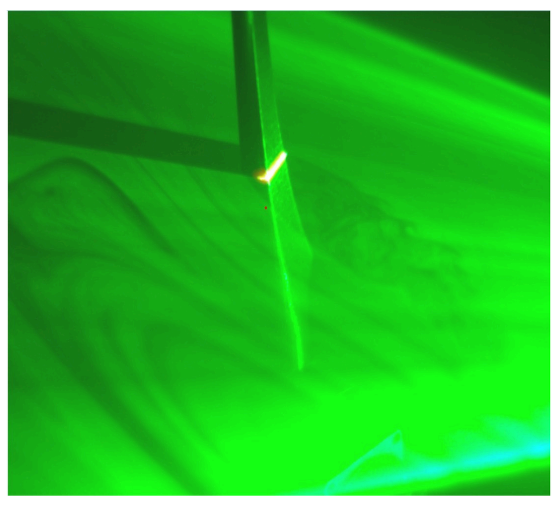

Figure 8. Image of Vortex around Blade 2 when it is still

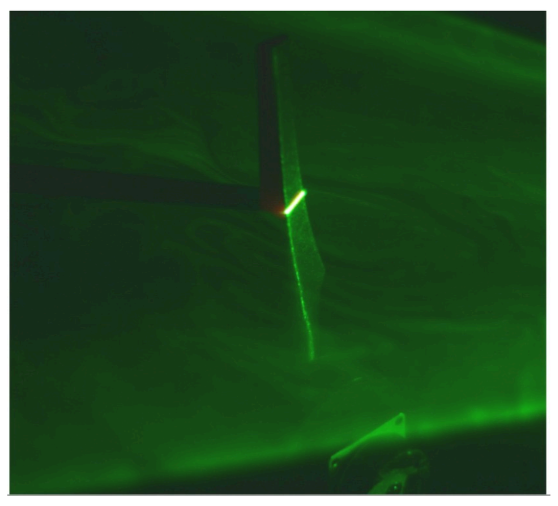

Figure 9. Image of Vortex around Blade 2 when it is in motion

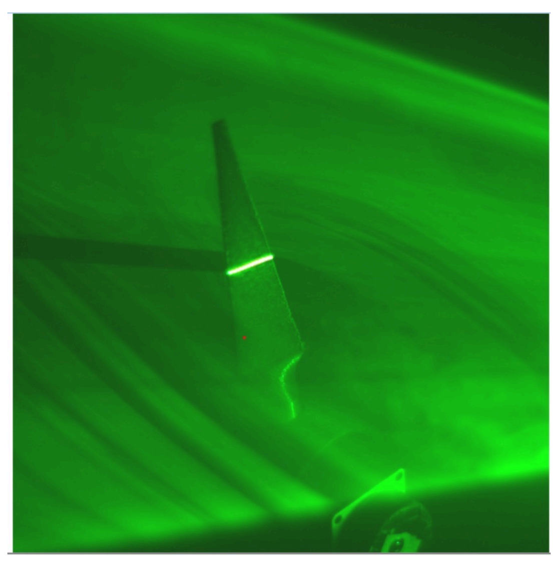

Figure 10. Image of Vortex around Blade 1 when it is still

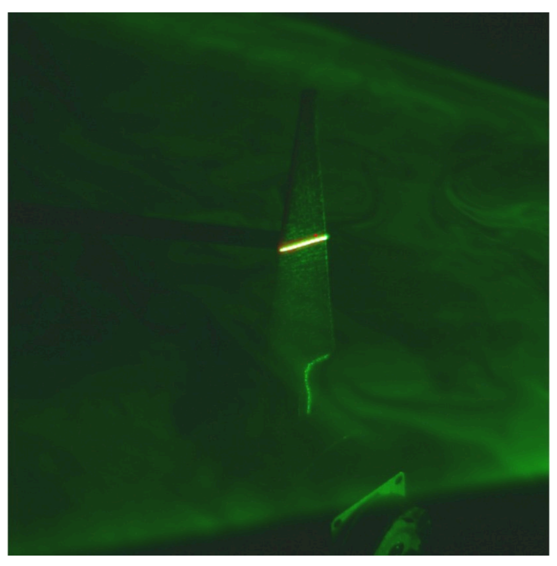

Figure 11. Image of Vortex around Blade 2 when it is in motion

Discussion

Observing the three sets of graph, there is generally a linear correlation between the output voltage and the wind speed which causes the turbine rotation. This indicates that the power generated has a roughly quadratic relationship with the wind speed since the power dissipated over a resistor is $\frac{V^2}{R}$

The results for blade 1 (figure 3) shows that position 1 resulted in a higher increase in voltage with increasing wind speed, although the minimum wind speed required for the blades to start rotating was higher than in position 2.

For blade design 2, a different result is seen as position 2 yielded a steeper voltage gradient with increasing wind speed (figure 4). However, position 2 also required a higher wind speed so that the blades would start rotating.

Design 3's results (figure 3) show that position 2 also yields a higher voltage gain with increasing wind speed. However, in this case, position 2 also has a lower required wind speed for the blades to start rotating.

Observing the air flow around the three blade designs, it can be seen that design 3 generates the most lift on the blade, allowing it to experience a greater force and rotate the fastest, thus allowing for a higher voltage the be produced as the generator is set in motion.

Comparing the three designs, blade 1 can be said to be the least efficient as it in general converts the least amount of wind energy to electrical at the same speeds as the other two designs. This may be due to the end of the blade being too pointed which reduces the vortices that may occur and generates less lift on the blade.

Design 2 is more efficient than blade 1 but almost a third less efficient than design 3. This may be due to the thickness of the blade compared to design 3. Additionally, the chord length of the cross-section at the tip is much larger than that of design 3 which may affect the lift it experiences.

Design 3 showed the highest efficiency which may be due to the thinness of the blade and a balance between how pointed the tip was and its chord length.

Conclusion

Of the three designs tested, blade 3 was the most efficient although all three blades were kept at roughly the same length. This may indicate that the optimal blade design for the horizontal wind turbine may be a relatively thin blade with a tapered end and an aerofoil cross-section.

As it relates to the setup for the experiment, it can be deemed a success as it was possible to integrate various blades with the hub and all other parts were able to correctly interface with each other.

Recommendations

Since only two angles were tested, the effect of angle of attack on efficiency cannot be generalized so more testing should be done with a wider range of angle of attacks.

The cross-sections of all the blades were not the same in this study so it would be beneficial to investigate the effect of blade length on efficiency compared, holding the cross sections constant.

The thickness of all three blades were not kept constant between the blades, so a test where this is done would be beneficial is seeing if the thickness played any role in the results.

Investigating if the hub designed played a role in the results would be beneficial.

The performance of vertical axis wind turbines were not measured but it would be ideal to test the performance of VAWTs against HAWTs.

Acknowledgements

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