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Experimental Study of Two, Two-Reversed, Three and Four Blade IceWind Turbine

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Abstract

IceWind turbine, an advanced sort of Vertical Axis Wind Turbine, was offered by an Iceland based startup. They manufacture it without any scientific research. As a new type, it needs more investigations to proof its claims; this paper examines experimentally its performance and conducts a parametric study. A new design for a two blade IceWind is made and optimized. A comparison between the offered two blade IceWind and Savonius wind turbine of similar swept area is carried out. Experiments are conducted varying the number of blade and established in a wind tunnel at five wind speeds from 6 to 14 m/s. Turbines are constructed using Aluminum pieces. Static torque in N.m and rotational speed in rpm are acquired using digital torque meter and digital tachometer, respectively. It can be concluded that, three blade IceWind turbine gives better performance in terms of aesthetics and noise. IceWind turbine shows similar performance to Savonius wind turbine with little higher values of static torque and rotational speed. Dynamic similarity, uncertainty analysis and comparison with previous data of Savonius turbines are included.

Keywords: IceWind Turbine, Savonius Wind Turbines, Wind Turbines, Experimental, Wind Tunnel.

1. INTRODUCTION

The use of renewable energy resources is a replacement to traditional fossil fuels; coal and oil. Alternative energy resources have a very light environmental footprint. They are the way to a less polluted world. Renewable energy resources may be found in sunlight, air, depths of the earth, and oceans. It is constantly replenished by natural means, and it simply cannot be exhausted. Wind, water, and solar power using existing technology are predicted to supply all of the world's energy by 2030 [1]. For example the Egyptian wind farm produces more than 15 million kWh/year [2, 3]. A wind turbine is used to capture the wind flow and converts it to a torque on the rotor. This model converts the kinetic energy of the air flow units captured as a mechanical energy of the turbine rotor (shaft) into an electric energy. These devices may be divided into two type’s horizontal and vertical axes.

IceWind is a new type of Savonius Vertical Axis Wind Turbine, see Figure 1. IceWind turbine is named after “Iceland” its home town. In its website [4], Iceland language “Islenska” appeared in the upper right corner. IceWind turbines can be installed on telecom towers and can be used for residential applications such as homes, cabins and farms [5].

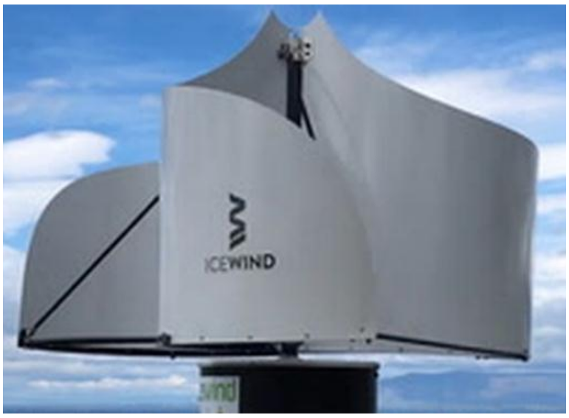

Figure 1. IceWind Turbine

Firstly, Aymane [6] introduced IceWind turbine. He revealed that IceWind turbine is as complex in manufacturing but its shape has a good looking. Additionally, noise of IceWind turbine is less than that of Savonius turbine. He emphasized that any product should show a good performance and should also have a wide acceptance from the community. He invited contributors to ask them about overall appearance, noise level, and efficiency. Eighty five percent of participants declared that IceWind turbine has less noise and better overall appearance than traditional Savonius. Afify [7] compared between the Savonius and the IceWind turbines numerically. The results were that IceWind turbine has a better performance than the Savonius turbine. The experimental performance investigation carried out by Afify [8] showed that the performance of the three-blade IceWind is better than the other designs.

Due to the lack of data for IceWind turbine to judge its performance, the Savonius wind turbine’s previous studies will be used for comparison. Many authors [9 - 14] studied turbine’s number of blade effect on its performance. Comparisons were made between two and three blade rotors. Furthermore, authors [15, 16] carried out experimental comparison and investigation of performance between two and three blades Savonius wind turbines. Finally, a two blade

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rotor gives higher efficiency and higher power coefficient.

Other work [17 - 19] had studied Savonius wind rotors and identified the various performance parameters to increase its efficiency. While [20 - 22] had studied the operating conditions on the starting rotation, reverse up rotation, power and torque coefficients. Other studies [23 - 25] studied the flow through a Savonius Vertical Axis wind turbine to study the behavior and to do a performance evaluation for the Savonius wind turbine under flow conditions. The performance of a two-stage two-bladed configuration of the Savonius rotor and the investigation of the optimal characteristics were subject to study [26].

Although IceWind and Savonius turbines are similar to each other as VAWT drag type, IceWind turbines proved that three blade are better than the two blade; while Savonius turbine proved that two blade are better.

The present work aims to investigate experimentally the optimum IceWind turbine number of blade. An IceWind turbine has been designed, manufactured and tested at our workshop. Turbine rotor height of 200 mm and diameter of 117 mm as shown in Figure 2 was studied. The models have no overlap or separation gap. The tests are performed inside an open circuit suction type low wind speed wind tunnel. Wind speed changes from 6 to 12 m/s. Furthermore, the results were verified with the previous readings of measurements of torque coefficient and power coefficient in the literature.

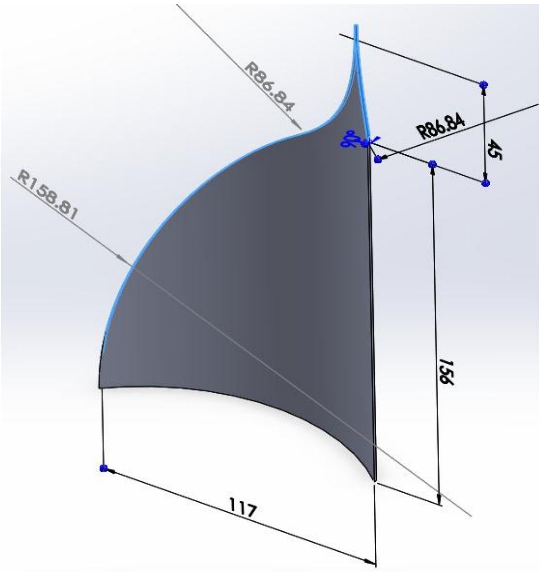


Figure 2. IceWind Blade. Final Design

2. EXPERIMENTAL WORK

The experimental investigation is performed on a test-rig, Figure 3 designed and fabricated at our laboratory. The experimental tests are carried out to clarify the best design of IceWind turbine.

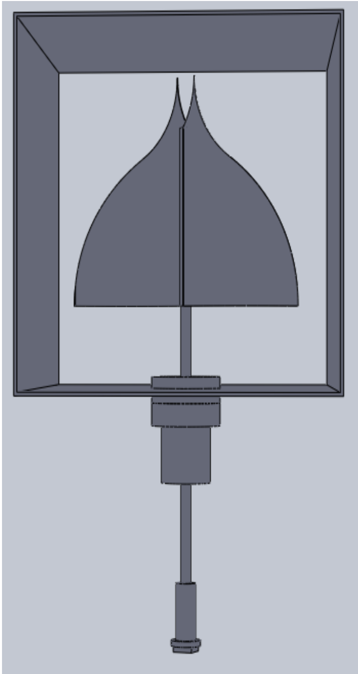


Figure 3. Schematic of the test rig

Experimental set-up layout has general arrangement shown in Figure 4. It consists mainly of the components shown in the Figure. Suction subsonic wind tunnel type and IceWind turbine.

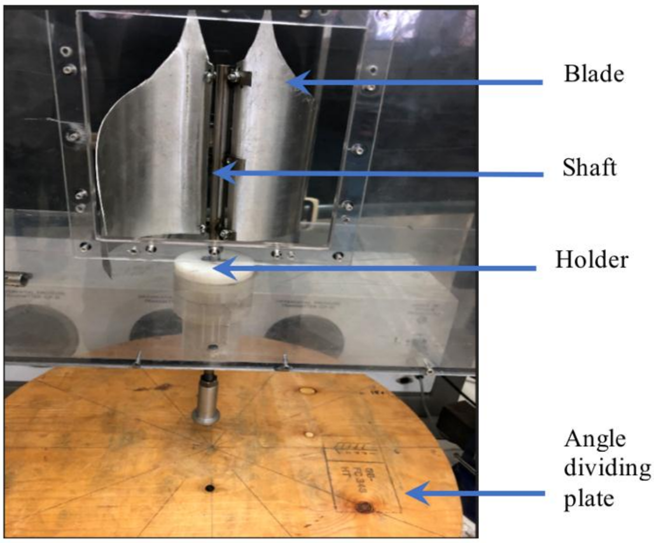


Figure 4. A photograph of the test rig

Most of experimental data needed in aerodynamics is produced using wind tunnels. A suction type Hampdin model H-6910-12 wind tunnel with a 30 x 30 cm test section was used to carry out the tests. This unit provides air speed of up to 8800 ft/min (100 mph). The wind tunnel has a control valve to adjust the wind speed. The fan is driven by an AC motor of 480 volt. The tested wind turbine place is at a distance of 50 cm upstream of the wind tunnel exit. The rotating rotor's center is maintained in-line with the center line of the wind tunnel exit area. This can be achieved through a mechanism facilitating the replacement of rotors with different geometries so that the center of rotor remains always in-line with the center of wind tunnel exit area.

IceWind blade forms from an incomplete half of a circle at their base. They are manufactured of Stainless Steel. This meant that in the present design starting from the barrel shape a rectangular block would cut from the inner side of the blade to make it looks like that of IceWind. SolidWorks constraint tools are used to find the radius that will satisfy the position of the tip of the blade as well as tangencies to the lower parts of the blade. The final shape of blade and its detailed dimensions are shown in the figures below.

The IceWind rotors are made from steel. Figures 5 to 6 show two blade IceWind turbines. Figures 7 and 8 show two blade reversed, Figures 9 and 10 show three blade IceWind turbine and finally, Figure 11 and 12 show four blade IceWind turbine. The angles between blade for two, three and four blade are 180º, 120º and 90º, respectively.

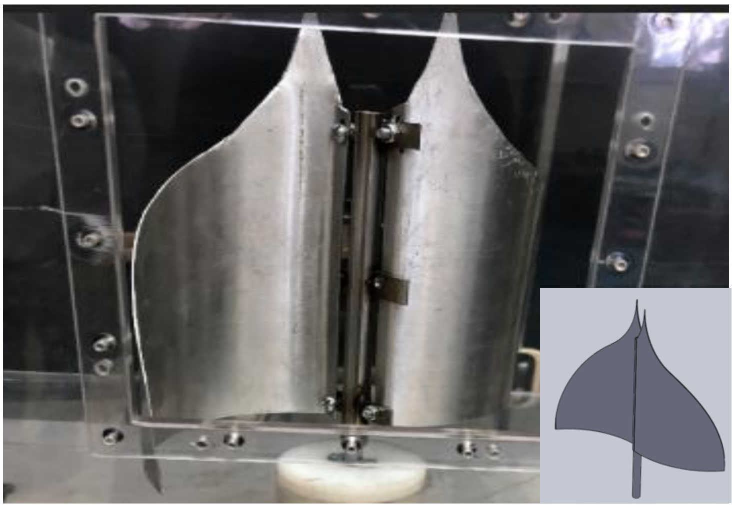
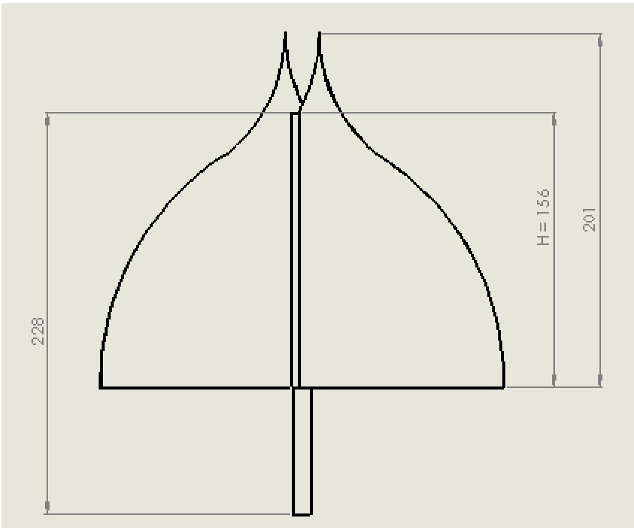
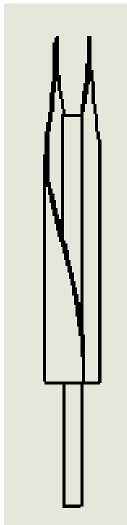


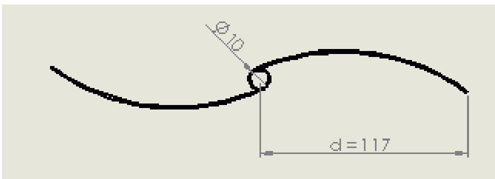
Figure 5. A photograph of tested two-blade IceWind turbine.



a) Elev.



b) Side view.



c) Plan

Figure 6. Two blade IceWind turbine’s three views (Dimensions in mm)

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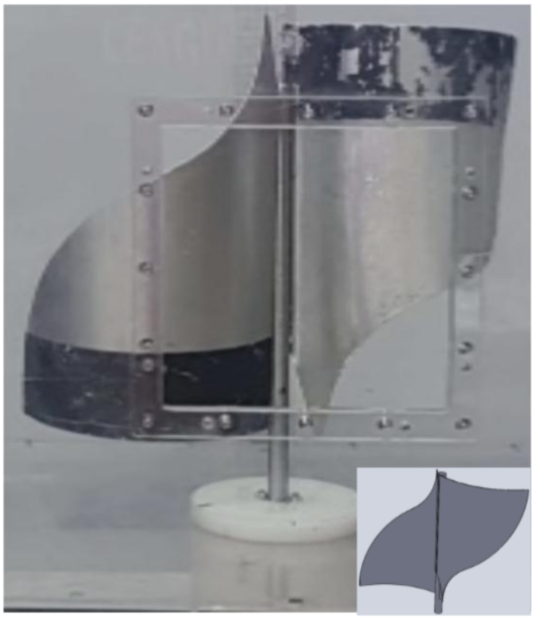
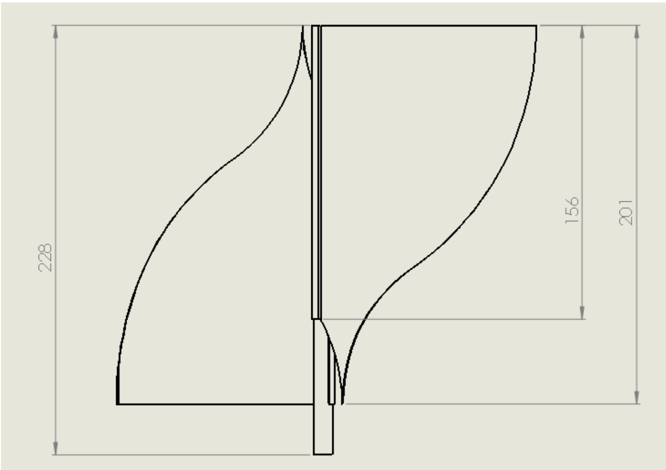
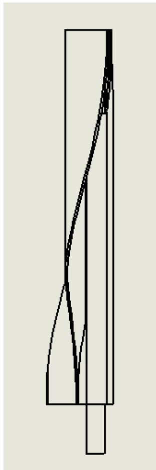


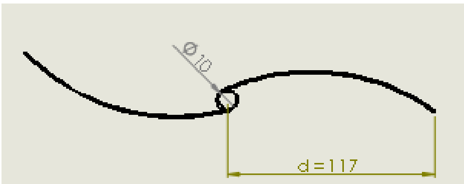
Figure 7. A photograph of tested two reversed blade IceWind turbine



a) Elev.



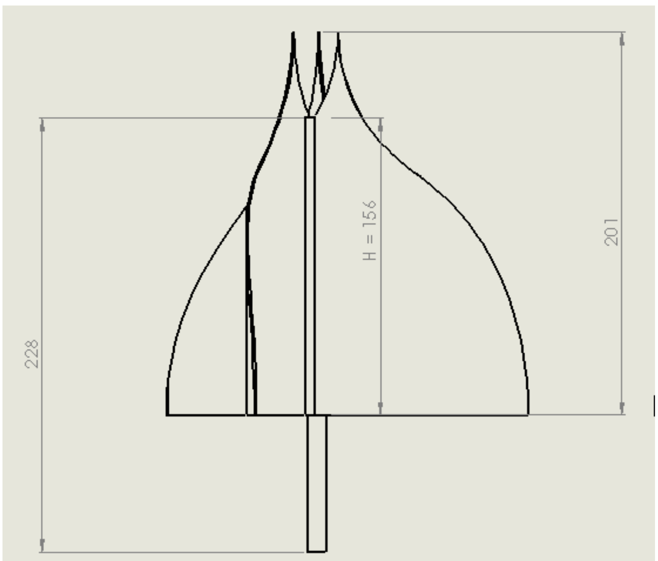
b) Side view



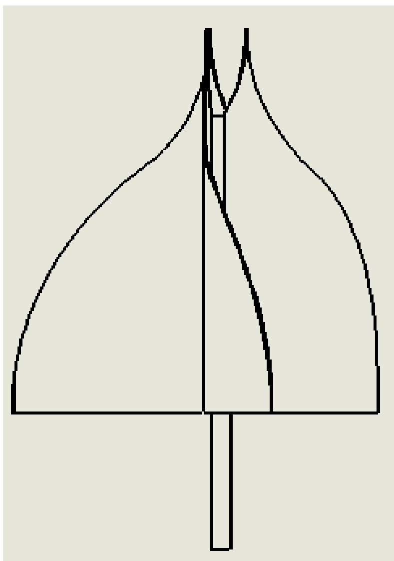
c) Plan

Figure 8. Two blade reversed IceWind turbine's three views (Dimensions in mm)

Figure 9. A photograph of tested three-blade IceWind turbine



a) Elev.



b) Side view

c) Plan

Figure 10. Three blade IceWind turbine’s three views (Dimensions in mm)

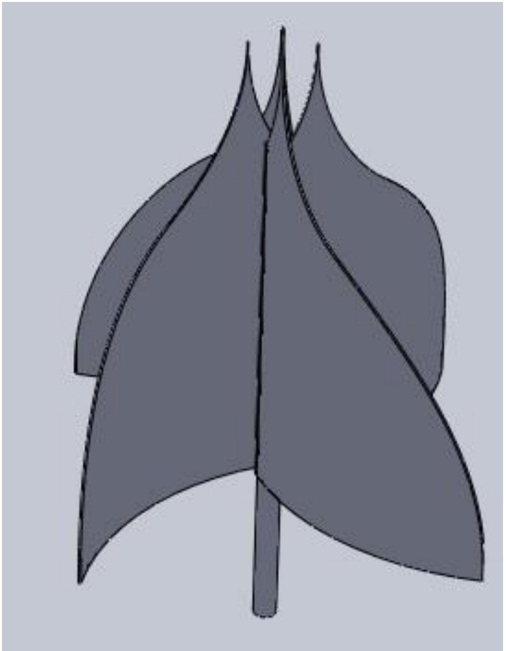
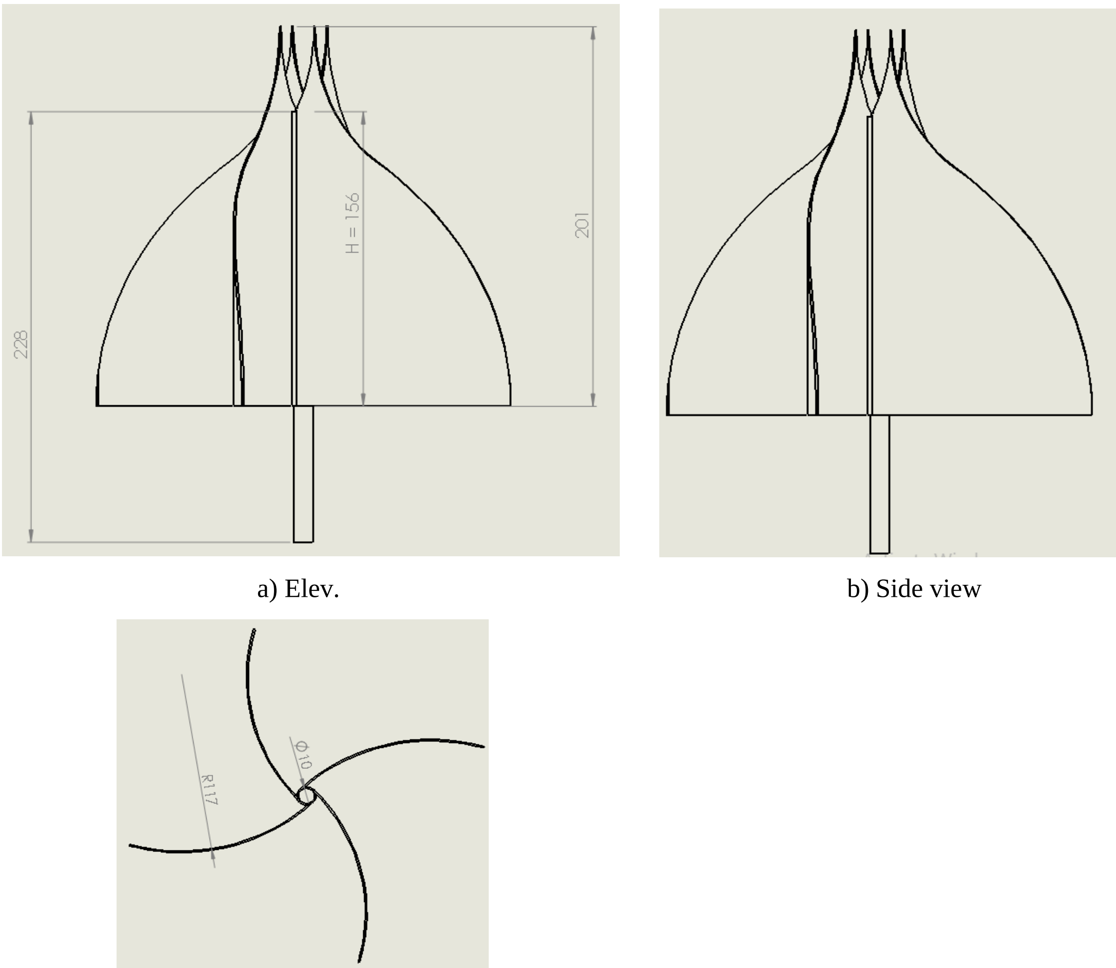


Figure 11. Four blade IceWind turbine



a) Elev.

b) Side view

c) Plan

Figure 12. Four blade IceWind turbine's three views (Dimensions in mm)

2.1 Measurements and instrumentations

The tests were performed at the test section in the wind tunnel. The wind tunnel test section's dimensions are 30 cm x 30 cm x 100 cm. Air velocities are measured using a Pitot tube, which calibrated at Faculty of Air Defense.

Digital torque meter (Kingsom KS-100) with a range from 0.015-1.00 N.m and a sensitivity of ±0.005 N.m is used to measure the Static Torque (Ts). It is calibrated by matching its readout to torque calculated for weight at a distance. A toque test head is used to mount the shaft.

Mastech MS6208B with sensitivity of ±0.1rpm is used to measure rotor's rotational speed. This digital tachometer has a laser ray pointed to a reflector fixed on the rotor blade whose speed is to be determined.

2.2 Experiment Procedures

1. Place the angle dividing plate below the torque meter device under the wind tunnel.
2. Attach the shaft in wind tunnel and install the IceWind blade (with the required arrangement).
3. Attach the end of the shaft to the digital torque meter test head.
4. Operate wind tunnel fan at a certain speed.
5. Use the digital torque meter device at each division starting from 0º until 360º and read the shown number on its screen (an average reading) in N.m. The zero angle is shown in Figure 13.

Figure 13. Turbine's zero angle.

6. Measure the freely rotate IceWind rotational speed using tachometer device (an average reading) in rpm.
7. Repeat steps 5 and 6.
8. Repeat steps 4, 5, 6 and 7 at each certain speed.

2.3 Calculations

Coefficient of static torque can be calculated as follows:

$$C_{ts} = \frac{T_s}{T_w} = \frac{T_s}{0.25*\rho*A_s*D*v^2} \qquad (1)$$

Where

C_{ts} = coefficient of static torque

T_s= actual static torque (N.m)

T_w = available wind torque (N.m)

ρ = density of air (kg/m^3) = 1.225 (kg/m^3)

A_s = swept area (from SolidWorks) (m^2)

D = IceWind rotor diameter (m)

v = wind speed (m/s)

3. RESULTS AND DISCUSSIONS

The experiments procedure was performed and tested in the wind tunnel and the required measurements were carried out to study the performance of the two, two-blade-reverse, three-blade and four-blade IceWind turbine. Comparisons between these designs were carried out to prove which one has a better performance in terms of the dimensionless parameter, static torque coefficient (*Cts*). Figures 14 and 15 show the plots of the wind speed versus the rotor speed (rpm) and average torque for the two, two-blade-reverse and three-blade IceWind turbines. Wind speed increases from 0 m/s to 14 m/s all the IceWind turbines were initiated and started to move. Cut-in speed is the speed at which the wind turbine starts to move. Cut-in speed for two-blade type of wind turbine was about (6 m/s).

Figure 14 shows high rotational speeds for all designs with the highest for the three-blade design. The reason is that, the slim rotor with a small diameter can get higher rotational speed but lower torque. On the other side, rotors with bigger rotational diameter produce bigger torque but lower rotational speeds. The measured data for the rotor speed had an error of ±1 rpm.

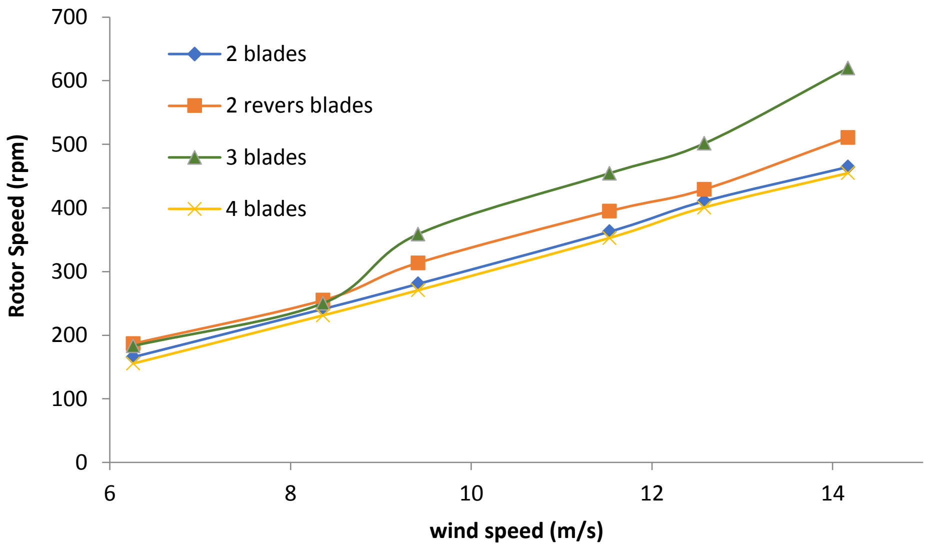


Figure 14. The rotor rotational speed (rpm) versus wind speed (m/s) for two, two-reverse, three and four blade IceWind turbines

Figure 15 shows the variation of average torque with wind speed for different IceWind designs, two-blade, two-reverse blade, three-blade and four blade. From the plot, it is clear that the four-blade turbine does not have the highest average torque, but on the contrary, it had the lowest. Instead, the highest torque was for the three-blade, followed by the two-reverse, then the two-blade.

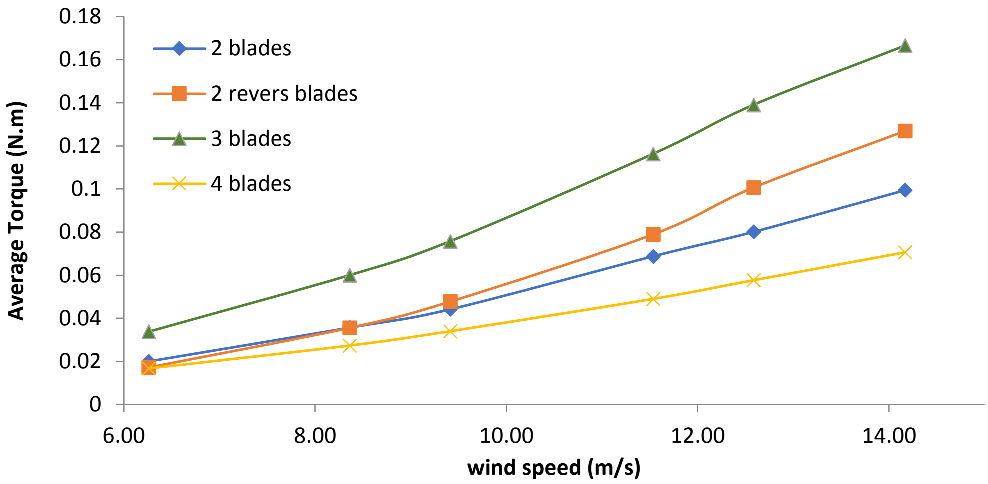


Figure 15. Average torque versus wind speed for two, two-reverse, three and four blade IceWind turbines

It was observed that, static torque measured at a wind speed of (V = 12.5 m/s) varies with the angle of rotation (α). The static torque is measured at every 30º from 0º to 360º. It appears that, static torque that can be produced during each revolution has an oscillatory function.

Figure 16 shows the change of static torque with angle of rotation for two-blade IceWind turbine for different wind speeds from 6 to 15 m/s. For all cases, static torque has two peaks at θ = 150º and 330º. Air velocity of 6 m/s had a static torque of lowest value, moreover, air velocity of 14 m/s had a static torque of highest value. It is noticeable that static torque values have repeated twice through angle θ range. This may be because of the existence of the two blade.

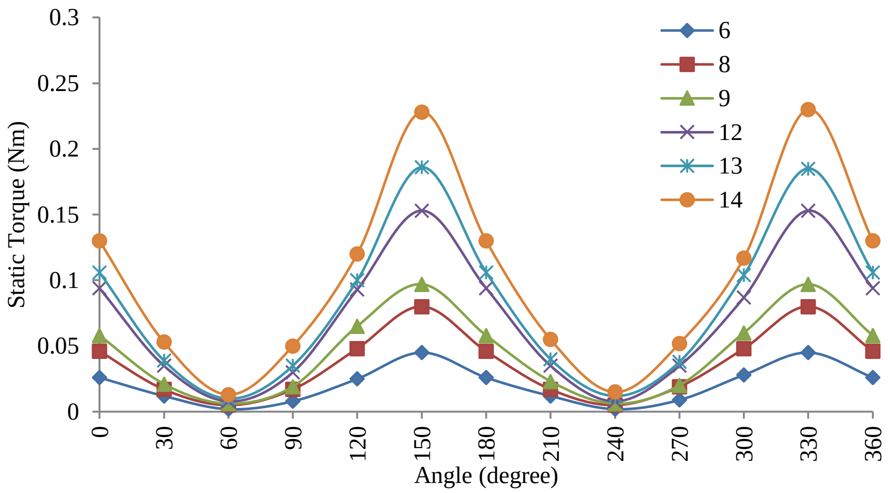


Figure 16. Static torque variation with angle of rotation for two blade IceWind-turbine.

Figure 17 shows the static torque variation with angle of rotation for two reverse-blade IceWind turbine. This experiment appears to be the opposite of the previous results of the two-blade turbine shown in Figure 16 in terms of the beginning, highest and lowest points. The peaks were at the angles of 120º and 300º.

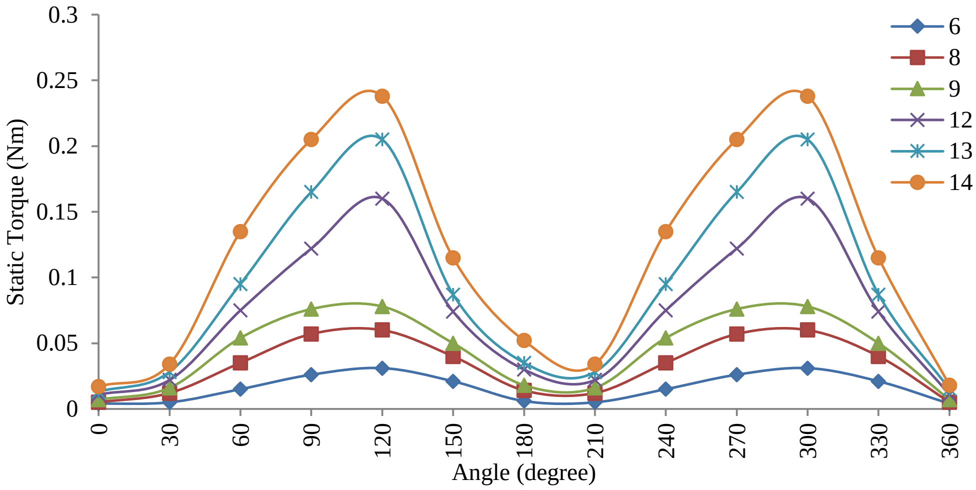


Figure 17. Static torque variation with angle of rotation for two-reverse blade IceWind turbine

Figure 18 shows the static torque variation with angle of rotation for three-blade IceWind turbine. As shown in the Figure, it consists of three peaks. The highest torque values are approximately at the angles of 60 º, 180 º and 300 º and the lowest torque values were at the angles of 90 º, 210 º and 330º.

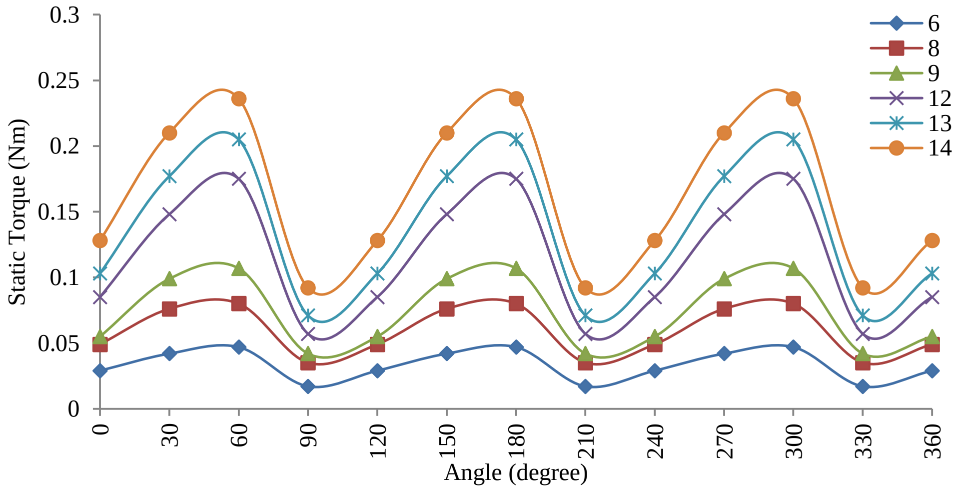


Figure 18. Static torque variation with angle of rotation for three blade IceWind turbine.

Figure 19 shows static torque variation with angle of rotation for the four-blade IceWind turbine. This experiment shows that, the four-blade is the least favorable design in terms of torque as it had the lowest torque values.

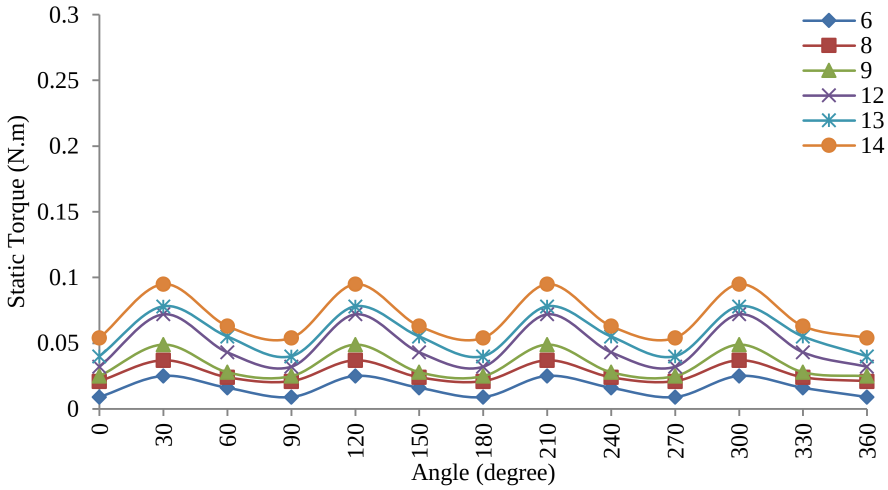


Figure 19. Static torque variation with angle of rotation for four blade IceWind-turbine.

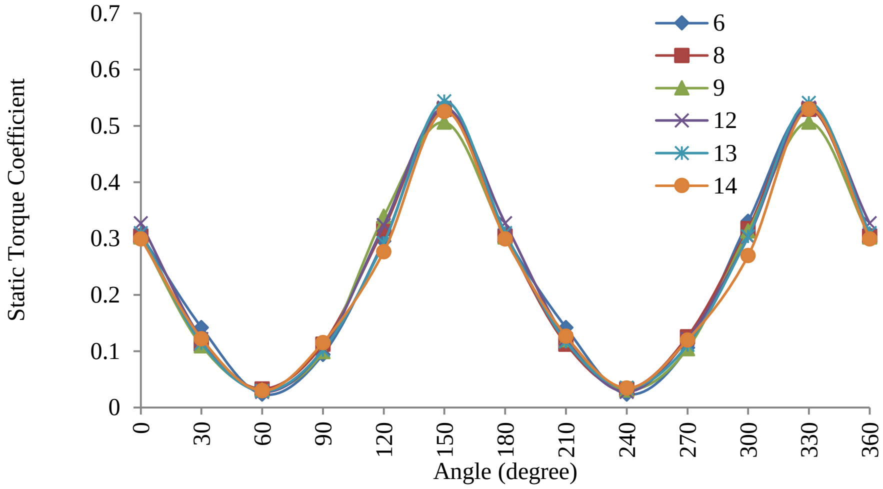


Figure 20. Static torque coefficient variation with angle of rotation for two blade IceWind turbine

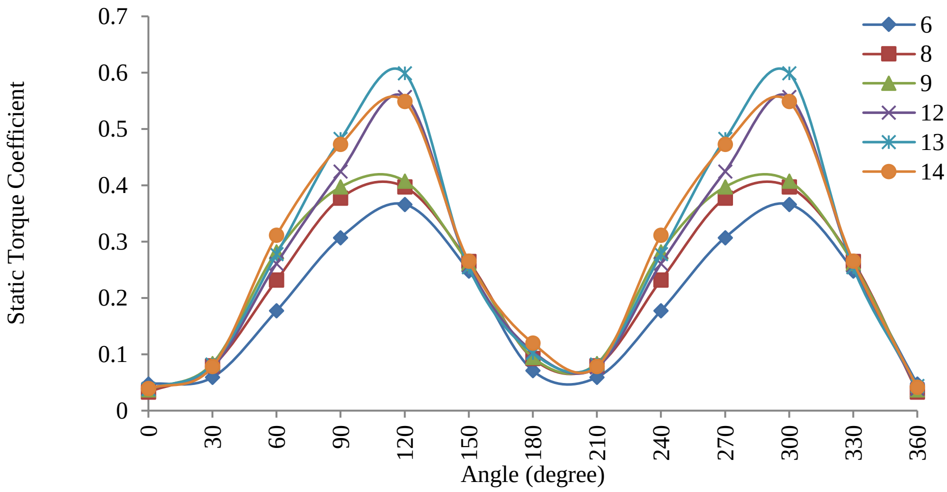


Figure 21. Static torque coefficient variation with angle of rotation for two-reverse blade IceWind turbine.

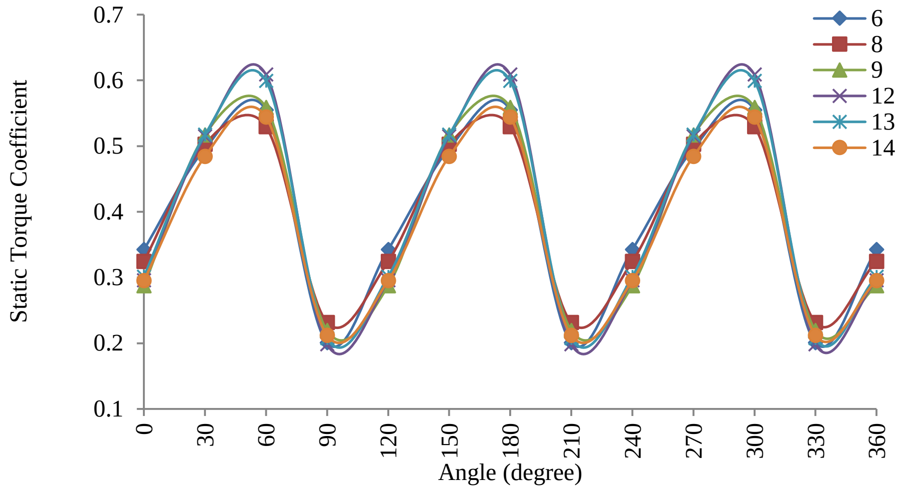


Figure 22. Static torque coefficient variation with angle of rotation for three blade IceWind turbine

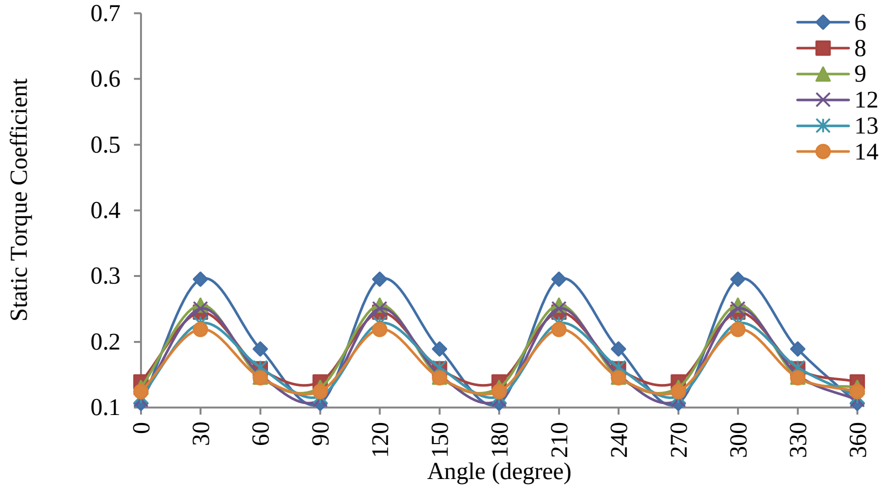


Figure 23. Static torque coefficient variation with angle of rotation for four blade IceWind turbine

4. UNCERTAINTY ANALYSIS

Uncertainty analysis [27] is performed to calculate the uncertainty values for coefficient of static torque (Cts) at confidence level of 95% using equation (1). Uncertainty Analysis of Coefficient of Static Torque for IceWind turbine has given values of 6% for two blade, two blade reversed, three blade and 15% for four blade.

5. COMPARISON WITH PREVIOUS WORK

Previous results [28, 29] of Savonius turbine are used to compare present results of coefficient of static torque. Comparison between two blade IceWind and Savonius turbines using static torque coefficient variations with angle of rotation are shown in Figure 24. Good agreement was achieved. Comparison between three blade IceWind and Savonius turbines using static torque coefficient variations with angle of rotation is shown in Figure 25. A very good agreement was achieved concerning a qualitative analysis.

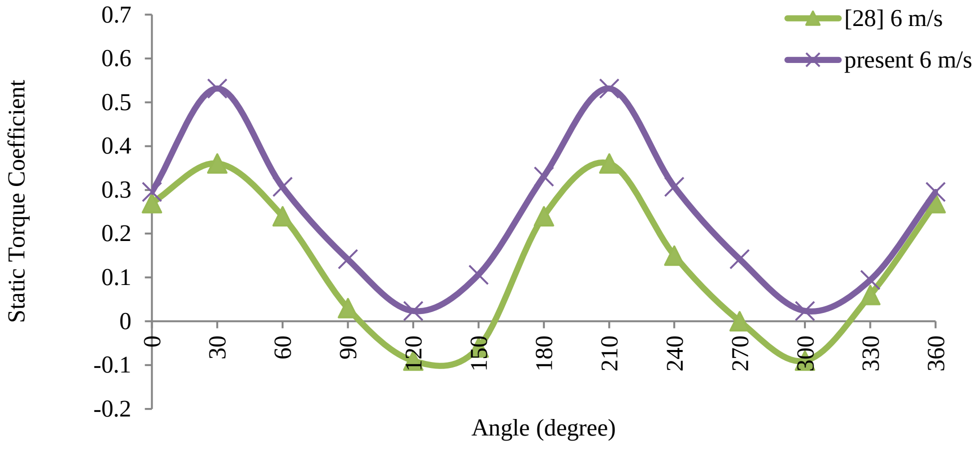


Figure 24. Comparison between two blade IceWind and Savonius turbines using static torque coefficient variation with angle of rotation

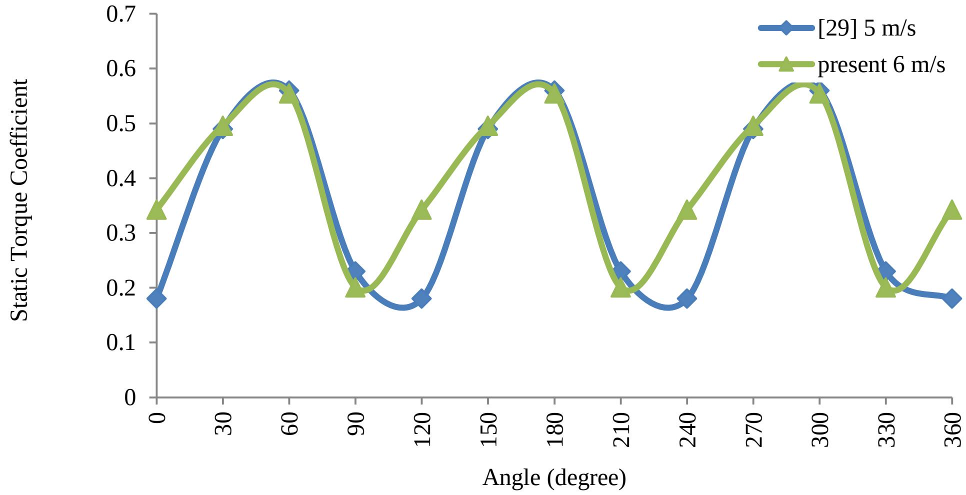


Figure 25. Comparison between three blade IceWind and three blade Savonius turbines using static torque coefficient variation with angle of rotation

6. CONCLUSIONS

The aim of this study was to investigate the performance of a new design of Vertical Axis Wind Turbine. Various IceWind turbine number of blade are experimentally discussed; two, two-reversed, three and four blade. Simplified model using Stainless Steel is built. The turbine is placed in the wind tunnel under five wind speeds (6, 8, 9, 11 and 12 m/s). Static torque, coefficient of static torque and rotational speed are determined to obtain the best performance number of blades. It can be concluded from the experimental results that three blade IceWind turbine gives higher static torque coefficients and rotational speed than two, two-reversed and four blade. Therefore, the three blade design is suggested to give a better performance.

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