Experimental Study Wind Turbine Performance of Straight-Savonius and Ice-Wind Type on the Similar proportion Aspect Ratio

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Abstract. The Performance of wind turbines at low speed can be improved by Ice-Wind model, particularly in self-starting conditions. Compared to a traditional wind turbine with two blades of the similar area and material, Ice-Wind can increase efficiency by 19%. Research on the Savonius turbine, particularly the Ice-Wind turbine, is challenging. It is because it has many restrictive parameters, such as the height, diameter, and area of the turbine blades. The Ice-Wind turbine shape is obtained by cutting a Savonius turbine. This process led to research on Ice-Wind turbines only under the similar parameters. The aspect ratio of a Savonius turbine has a significant effect on the speed, mechanical power and static-torque produced by the wind turbine. The research was done on Savonius and Ice-Wind turbines with the similar aspect ratio. The results show that the speed, power factor and efficiency of the Savonius turbine are higher than those of Ice-Wind. However, Savonius produces a smaller static-torque coefficient value than Ice-Wind. The results of this research contrast with other studies comparing Savonius and Ice-Wind turbines. In other researches, Savonius and Ice-Wind turbines have the similar area but different aspect ratios.

1. Introduction
The application of Wind-turbines is an alternative way to reduce the consumption of conventional fuels. The wind turbines are clustered in 2, depending on the axial stance, that is, and the wind-turbine of the vertical axis (VAWT) and the wind-turbine of the horizontal axis (HAWT). HAWT models is more efficient and has more power than Straight-Savonius [1]. However, Straight-Savonius is more commonly used than HAWT due to some benefits. Straight-Savonius is classified as VAWT which has capability to do self-starting process. In addition, it has little noise and does not require a tower up to back it. This condition is close to the ground, so it facilitates the easiness of Savonius’ reduction [2].

The process of manufacturing the Straight-Savonius is simple, and the turbine consists of two semi-circular blades connected to the axis with half-cutting of the cylinder.

Straight-Savonius produces electricity from the dragging force which put the blade into a motion. Upwards free stream puts into a motion the blade and leads to a higher power than reverse it for the concave shape. The drag from the reverse blade produces negative static-torque that provide resistance to rotation of the wind-turbine shown in fig. 1. Increasing the positive static-torque on the front blade increases the free-stream velocity and leads to greater blockage caused by the reverse blade [3]. In addition, the net power of the wind-turbine has been improved as the free-stream velocity increases the static-torque until it reaches the optimum point. After receiving the optimal score, the actual static-torque decreases due to increasing negative static-torque on the reverse blade as a locking effect. Several improvements can be applied to improve the power and efficiency of wind turbines, including optimization of shape[4], number of blade[5], stages [6] and modified geometry[7].
The reshaping of the Straight-Savonius blades was made by cutting the end of the turbine[7], [8], twisting the blades [9] and adding slot vents to the wind-turbine blades[10], [11]. Helical type blade shape changes are commonly applied to improve aerodynamic forces. This model is created by twisting a straight blade into a spiral model at a specific angle. In a numerical simulation of Saad, a twisted Straight-Savonius was tested at a rotor angle of 360° to determine the fluid flow characteristics of the wind-turbine from each angle. Applying the Straight-Savonius twist blade can increase the static-torque of the rotor-turbine over the existing savonius. The Straight-Savonius blade twisted shape allows the wind-turbine blades to best capture the flow of fluid and reduce vortices that occur behind the blades. This situation may enhance the auto-start capability of Savonius twisted wind turbines [9]. This can be improved by reducing the Straight-Savonius because the size of the vortex between the blade slot vent blades can be reduced. It perform optimally when rotating with 2-blades. The application of overlap can improve the performance of a wind-turbine by 10,15%. It can be done by subtracting the negative static-torque caused by the blocking effect.

![Image](Image)

**Figure 1.** Free stream flow across a Straight-Savonius[3]

The idea of using overlap was emerged by giving vent slots for the blades. Slotted blades can improve performance of wind-turbine in the form of power coefficient ($C_P$) up to 14.4%[11]. The reducing of negative static-torque can be done by cutting the tip of Straight-Savonius into a semi-triangular shape. A common form of wind-turbine used is in the form of a tapered model of Ice-Wind. A 10% area reduction Tapper Straight-Savonius fails to reduce performance, reduce performance, and reduce the size of vortices formed upstream of the wind-turbine[12]. Therefore, the Ice-Wind model can improve the performance of wind turbines at low speeds, especially in self-starting conditions[13]. Ice-Winds are larger in diameter than Tapper and existing wind turbines. Sometimes the height is longer than the rotor diameter ($H / D > 1$) and the flow of fluid flowing from upstream can have enough energy to push out the vortices formed between the blades. Ice-Wind allows two blades of the similar area and material to increase efficiency by up to 19% on existing wind turbines. Straight-Savonius performance improvements occur at 0 2.5 m / s and begin to show performance degradation at speeds of 3 m/s. Other studies conducted experimentally by T. Gad (2020) under normal conditions revealed that the Ice-Wind with three blades produced the highest speed than a different number of blades [14]. The experiment also stated that Ice-Winds with reverse blades had higher angular velocity and static-torque than Ice-Winds with conventional blades. However, the static-torque generated by the Ice-Wind is higher than regular Savonius and reach optimum condition at 4 m/s[15]. An increase in the power coefficient occurs with an increase in the static-torque of the wind-turbine blades until an optimum is reached. Then, as the fluid velocity increases in magnitude of the vortex, the power factor for reducing angular velocity of the turbine decreases. The vortices formed between the Ice-Wind blades in a wind-turbine with an aspect ratio ($H / D > 1$) have a larger size than existing Straight-Savonius[16].

The study of Straight-Savonius, especially Ice-Wind, is very difficult because there are many limiting parameters such as the diameter, height, area, etc. of the wind-turbine blades. The shape of the
Ice-Wind is made by cutting a Straight-Savonius. In this process, the study of the Ice-Wind is run only on one and the similar parameters. Therefore, the diameter and area are different for the Ice-Wind of the similar height as the conventional reference Straight-Savonius. The ratio of the Straight-Savonius has a great impact on the angular velocity, mechanical power and static-torque generated by the wind turbine. The higher the ratio of the Straight-Savonius, the higher the power coefficient of the wind-turbine[16]. Some of studies performed on Ice-Wind have been conducted in the similar wind-turbine domain as the Straight-Savonius used as a reference. Latest studies have shown that Ice-Wind has the similar area as Straight-Savonius by enlarging the original size of the Straight-Savonius blade being cut[7], [17]. Models made in this way produce Ice-Wind with a larger diameter than the reference diameter of the Ice-Wind. A previous numerical simulation conducted under unsteady conditions comparing the sizes of the similar Ice-Wind and Straight-Savonius produced a higher angular rotation than the Straight-Savonius with the Ice-Wind turbine starting condition in lower velocity[7]. The Mansour and Afifi [16] study compared Straight-Savonius with the exact similar area and diameter as the Ice-Wind. Within this research also shows that The Ice-Wind turbine gain higher static-torque than the Straight-Savonius. However, in this research, the Straight-Savonius is lower in altitude than the Ice-Wind aspect ratio = 0.9375 and Savonius aspect ratio = 0.708375[16]. No studies have been published on the performance of Ice-Wind and Straight-Savonius with the similar aspect ratio. This study discusses performance comparisons between Straight-Savonius and Ice-Wind with the similar aspect ratio. Performance data is presented in terms of coefficient output (Cp) and static-torque (CQ) generated by the Straight-Savonius and Ice-Wind. In this experiment, we also discuss wind-turbine performance data expressed as a function of free flow velocity in the TSR graph.

2. General Setup

2.1. The Model Setup

The experiment was performed using Straight-Savonius and Ice-Wind 3-blade turbines. The Straight-Savonius used in this experiment has 3-blades with end plates on both side ends. The blades of Straight-Savonius are constructed of split diameter 6.5” Pipe made of PVC. Ice-Wind consist of Straight-Savonius based cuts referenced from sketches of the similar diameter and height. In this experiment, the Straight-Savonius wind turbine has an identical Aspect Ratio with Ice-Wind turbine where the H/D = 0.5. This Ice-Wind is assembled to the shaft without end plate. The installation of an Ice-Wind without an end plate is aimed at reducing the weight of the wind-turbine as it spins. Detailed dimensions and figure of the Straight-Savonius are shown in Figure 2 and Table 1. An Ice-Wind cut sketch is detailed in Figure 3.

![Figure 2](image)

**Figure 2.** (a) 3D model; (b) sketch of a Straight-Savonius in midplane cut

| Table 1. The size of the Straight-Savonius. |
|-------------------------------------------|
| **Size**                                  |
| r=165 mm                                  |
| Do=345 mm                                  |
| Do=379.5 mm                               |

3
| Parameter                      | Value   |
|-------------------------------|---------|
| Blades Diameter (d)           | 0.165 m |
| Height                        | 0.330 m |
| Endplate Diameter (D₀)        | 0.3795 m|
| Rotor Diameter (D)            | 0.345 m |
| Do/D                          | 1.1     |
| Aspect Ratio (H/D)            | 0.5     |
| Endplate thickness            | 0.002 m |
| Rotor Shaft (S)               | 0.015 m |

2.2. Setup of Experimental

During the experimental tests, the wind-turbine was installed on a hollow iron support shaft. The test is run in an enclosed room with a fan or blower installed at a certain distance before the turbine. Within these experiments, a wind-turbine was tested using external flow. The free flow velocity is 2 to 6 m/s. The alteration in free-stream velocity is measured using an anemometer. It is installed previously in the test section. Within these experiments, the performance of a wind-turbine is shown in terms of angular velocity and static-torque. The process is implemented by using a spring scale connected to the wind-turbine with a rope. The static-torque is measured when a load is applied to the wind-turbine that can stop the rotation of the wind-turbine[18]. Angular Velocity of wind-turbine measurements were made by using a digital tachometer as in Figure 4.

3. Calculation of Data Performance
The important data acquired of the measurements in this research are the free-stream velocity, the angular velocity of the rotor wind-turbine and the force from wind-turbine loads. The data performance of static-torque and mechanical power are secondary data (2nd) obtained by primary data (1st) processing. Following expression is used in order to calculate the secondary data (2nd).

\[ P_m = \omega . T \]  

Output referenced in equation (1) is the mechanical power \( P_m \) of the wind-turbine attained by shaft rotation. It is attained from \( \omega \) and static-torque. Static-torque calculation can be acquired from equation (2). The force \( F \) that moves the shaft is the wind beauty across the wind-turbine at the diameter of the blade \( d \) and is calculated by reducing the mass of the load on the wind-turbine on the scale of the spring alone.

\[ T = F . d \]  

\[ \omega = \frac{2 \pi N}{60} \]  

\[ F = (m - s) . g \]  

\[ TSR = \frac{\omega . d}{v} \]  

\[ A_s = D . H \]  

\[ C_T = \frac{T \omega}{\rho . D . H . v^3} \]  

\[ C_Q = \frac{T_{actual}}{\frac{1}{2} \rho . A_s . d . v^2} \]

with,

- \( D \): Wind turbine diameter (m)
- \( A_s \): Frontal area (m²)
- \( v \): Free-stream velocity (m/s)
- \( T \): Static-torque wind-turbine (Nm)
- \( F \): Force on turbine (N)
- \( \rho \): Density(kg/m³)
- \( \omega \): Angular velocity (rad/s)
- \( C_Q \): Static-torque coefficient
- \( s \): spring balance reading (kg)
- \( N \): angular velocity(rpm)
- \( m \): Load mass (kg)
- \( g \): gravity acceleration (m/s²)
- \( TSR \): Tip speed ratio
- \( C_T \): Pressure coefficient
- \( d \): Blade diameter (m)
- \( H \): Wind turbine height (m)
- \( T \): Static-torque of wind-turbine (Nm)
- \( A_s \): Frontal area (m²)

4. Results and Discussion

4.1. Results

Results attained in this experiment were divided into 2 types of data. It was called by primary data (1st) and secondary data (2nd). Preparatory data such as the angular velocity, wind speed, and load on the wind-turbine are obtained directly from measurement. However, in this experiment, the main data graphed is the angular velocity of the wind-turbine, which varies as a part of free-stream velocity.

As shown in Figure 5(a), the alteration to the TSR free-stream velocity function indicates a decrease in the trend line. Figure 5 (a) corresponds with Figure 5 (b). The decrease in TSR value is caused by an increase in free-stream velocity, which can increase the angular velocity, as shown in Figure 5 (b). Value of TSR is acquired separately for the free-stream and the angular velocity. Under this condition, the TSR value decreases and the rotation speed increases. The alteration in the angular
velocity of the wind-turbine as a part of the free-stream velocity is shown in Fig. 5(b). This graph shows that the angular velocity produced by the wind-turbine changes as the free-stream speed increases. The free flow speed of 3 to 5 m/s, the addition in the angular velocity of the wind-turbine is on the lower level compared to other speed ranges. The difference data between the free-stream rate and the rotation rate is reprocessed as ancillary data in the TSR.

![Figure 5. (a) TSR of the wind-turbine and (b) Angular velocity](image)

In this experiment, the performance of the Straight-Savonius and Ice-Wind is shown as the $C_Q$, $C_p$ and TSR shaft efficiency as shown in Fig. 6, 7, 8. As shown in Figure 6, the static-torque coefficients generated by the Ice-Wind and Straight-Savonius have a convex trend line. Straight-Savonius generate lower static-torque compared to Ice-Wind. This result shows that the net static-torque generated by the Ice-Wind is higher than that of the Straight-Savonius. As shown in Fig. 7, the coefficient output value generated by the Straight-Savonius is higher than that of Ice-Wind. However, the $C_p$ values of these 2 wind-turbines produce similar trendlines. In the efficiency graph shown in Fig. 8 efficiency curves of the 2 wind-turbines are formed. This graph shows that the efficiency of the Straight-Savonius is higher than that of Ice-Wind, which has a maximum efficiency value of 45%. Nevertheless, the graph shows that the Ice-Wind can spin at low speeds in the TSR of 0.5-0.8 range. By comparison, the Straight-Savonius can operate optimally in the 0.65-0.85 higher TSR range. The efficiency of turbine discussed in this paper is the dynamic efficiency acquired by comparing dynamics power and power of wind.

![Figure 6. Coeff. of static-torque as Tip Speed Ratio Function](image)
4.2. Discussions

Result attained in the experiment was separated into (1st) primary data and (2nd) secondary data. (1st) Primary data as introduced earlier, Ice-Wind experiment is fairly tricky due to the many limiting parameters that include wind-turbine blade diameter, height, and area. The other settings for displaying data, such as TSR, also affect the attribute of the Ice-Wind experiment on rotating wind-turbines could be done under normal or abnormal conditions. Under normal conditions, studies of the primary data Straight-Savonius and Ice-Wind turbines were performed simulating a wind-turbine at rest with a change in angle of attack 360°[19]. Under normal conditions, this is the ideal condition for use in wind-turbine case studies. Studies conducted under abnormal conditions have some differences in cognizance in the tests. The simulation results are displayed as a function of TSR, which is the ratio of the free-stream velocity to the angular velocity of the wind-turbine blades. The results of TSR can be attained in 3 ways. Tests in the study of some Straight-Savonius or Ice-Wind, the first method, are performed with various changes in free-stream velocity as the rotor-turbine rotates in steady state. The 2nd method, the TSR value is acquired by testing the wind-turbine. Testing can be performed at the various angular velocities while the rotor-turbine is driven at a constant free-stream velocity[18]. Next method is the 3rd method. TSR data, can be attained by testing the Straight-Savonius and Ice-Wind until it reaches a certain speed in a stationary state[7]. The data acquisition process of this research is carried out using Method 1 to measure the data as it passes through the state conditions of the wind-turbine itself. Therefore, this research compares the characteristics of wind-turbines with different free flow velocities.

In this experiment, Straight-Savonius and Ice-Wind with the similar aspect ratio were targeted. The results show that Straight-Savonius produces more high-power factors, angular velocitys, and
efficiencies compared to Ice-Wind. However, the value of the static-torque produced by Straight-Savonius is on the lower level compared to Ice-Wind. The result of this experiment is divergent with other researches. The experiment of Ice-Wind performed by T.I. Gad (2020) states that an Ice-Wind with 3-blades creates the highest speed compared to any other number of blades[14]. This research also showed that Ice-Wind with the reverse blades have higher static-torques and angular velocities compared to Ice-Wind with ordinary blades[15]. For the wind-turbine with an aspect ratio (H/D) > 1, the size of the vortexes formed between the blades of Ice-Wind is more immense compared to ordinary Straight-Savonius[16]. A research by Afify and Mansour [16] compared an Ice-Wind with similar area and diameter Straight-Savonius. The results also shows that Ice-Wind generate higher static-torque than Straight-Savonius[16]. According to other experiment, Straight-Savonius and Ice-Wind have the similar the aspect ratio. Also, the area of the two wind-turbines is created separately. It is the main reason why the final results of this experiment are different.

5. Conclusions
Within this experiment, the data acquisition was divided into 2 separately way. The first one is according to primary data and the latest one is secondary data. Preparatory data such as the angular velocity, wind speed, and load on the wind-turbine are obtained directly from measurement. The experiment was performed on an equal proportion of Straight-Savonius and Ice-Wind. According to the results, Straight-Savonius turbine has higher power coefficient, angular velocity, and efficiency compared to Ice-Wind turbine. However, Straight-Savonius wind turbine has lower the static-torque coefficient values compared to Ice-Wind turbine. The final results from this particular research are divergent compared to another research of Straight-Savonius and Ice-Wind. According from other research, Straight-Savonius and Ice-Wind have the similar area yet different proportions.

6. References
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