The Effect of Cylinder Type I-65° Staggered Upstream Convex Blade on the Aerodynamic Performance of the Savonius Turbine

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Abstract. The Savonius turbine has advantages, including a simple design, unfettered incoming wind direction, can spin at low wind speeds, and start rotation without additional equipment. However, this turbine design has low efficiency, so many researchers have tried to improve it. The primary research in this report is one of the efforts to upgrade the performance of the Savonius turbine in the category of adding external devices experimentally. An I-65° cylinder type with diameter $d/D = 0.5$ is placed upstream of the Savonius convex blade at a distance $S/D = 1.4$ with a staggered angle $-10° \leq \alpha \leq 40°$ at Reynolds number $Re = 10.3 \times 10^4$ correspondence to freestream velocity $U = 5$ m/s. The performance of the standard Savonius turbine will be compared with a turbine that has installed a cylinder type I-65° upstream convex blade based on the power and moment coefficient. The static moment also is compared to identify the self-starting ability. The experiment results show the stager angle $\alpha = 40°$ as the optimal angle with an increase in the coefficient of power of 12%. For static torque measurement parameters, the results also show an increase in performance where the turbine rotation angle with negative torque decreases.

Keywords: Savonius · Coefficient of Power · Coefficient of Moment · Static Torque · Cylinder I-65

1 Introduction

This project was carried out as a form of participation in the search for renewable energy sources, which are currently very popular worldwide. Furthermore, environmentally friendly energy consumption is prevalent because of human awareness of environmental threats in the future [1]. Then this underlies the importance of research on various types of renewable energy sources to reach their respective optimal points. This research report is about improving the aerodynamic characteristic of the Savonius wind turbine. This scope is widely assessed to achieve an optimal geometric design and extract maximum wind energy. Nevertheless, the Savonius turbine is still a popular research object because of its inefficiency compared to other turbine types [2].

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Savonius turbine is also defined as a drag-type turbine. Because it rotates based on the distinction in positive pressure drag force at the advancing blade and negative pressure drag convex blade [3, 4]. This research aims to increase turbine performance and reduce negative pressure drag by installing cylinder-type I-65° staggered upstream convex blade. The dominant drag force in the advancing blade area will be proven to increase the drag-type performance of this turbine. Several previous studies are presented in the following section to meet the sustainable research.

The researcher [5] studied a Savonius turbine with several blade shape variations, the number of blades, and the stage numerically. 3D simulation is done with Ansys software with an aspect ratio of $D/H = 1$. The findings are *Cpmax* up to 0.2, and the optimal blade number and stages are two and three, respectively. The study by [6] focuses on high-pressure drag and loss of lift in vertical-axis wind turbines. The double multiple stream tube (DMST) approach is used numerically to solve the problem. The results show that the DMST approach increases the torque coefficient for most turbine blade azimuth angles. The torque coefficient is an indicator of self-starting capability that shows the level of responsiveness of the turbine to the wind without the help of an external device. The optimization of the power coefficient in the blade shape modification category is studied numerically by [7]. The result achieved a 39% improvement of the *Cp* higher than conventional Savonius.

Several efforts to improve efficiency that have been described above leave room for further research in this study. That is by installing an additional configuration of the cylinder type I-65° to reduce the drag force on the convex blade. This method is determined based on research reports from [4, 8, 9], where the type I-65° cylinder can reduce the main cylinder's pressure drag by delaying the separation point. Finally, the results of this study are applied experimentally to reduce pressure drag on the convex blade with modifications to the stagger angle.

2 Methods

2.1 Experimental Arrangements

Figure 1 and Fig. 2 show the experimental arrangement Savonius turbine with the cylinder I-65° staggered upstream convex blade. In this case, the I-type cylinder is small with $d/D = 0.5$ in diameter, trimming each side 65° perpendicular to the horizontal axis. The model was 3D printed with $Ds = 320$ mm in diameter and height $H = 305$ mm, corresponding to the aspect ratio $AR = 0.95$. The turbine has no e-gap and is equipped with endplate $De/D = 1.10$ compliance with the optimum geometry reported by [10]. The cylinder I-65° set within the distance fixed at $S/D = 1.4$ relative to the blade diameter and staggered angle $-10 \leq \alpha \leq 40$. The freestream velocity set at five m/s corresponds to the Reynolds number $Re = 10.3 \times 10^4$ and blows up from the exhaust of the wind tunnel.

Figure 3 shows the experimental setup, where the turbine stands 230 cm from an exhaust wind tunnel and 20 cm from it, the honeycomb installed with the task ensures the airflow is as uniform as possible. This distance was calculated and tested based on the uniformity assessment. Omega type HHF141 measures wind speed at five horizontal and vertical points at 200–250 cm. This method verified that the uniform windspeed

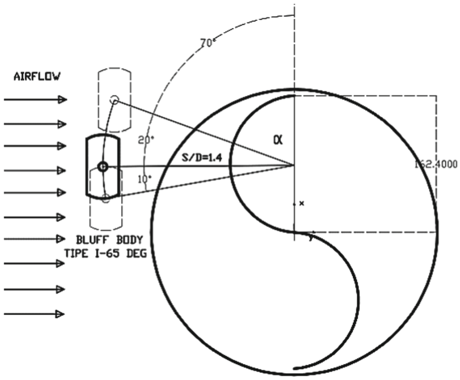

Fig. 1. The Savonius Turbine configured with I-65° cylinder type staggered upstream convex blade

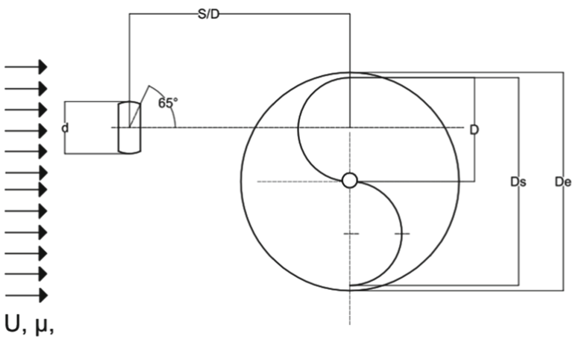

Fig. 2. The experimental schematic diagram and the symbols to determine the dimension and geometry of the Savonius turbine.

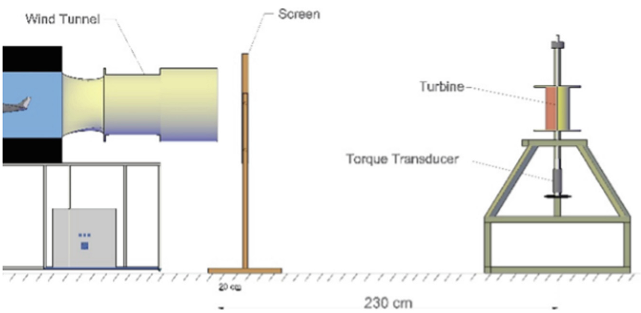

Fig. 3. The experimental conducted in the external flow using the wind tunnel outflow within a specific distance to the Savonius turbine.

for both axes is 230 cm with an average of five m/s. Figure 4 illustrates the uniformity assessment conducted in this study.

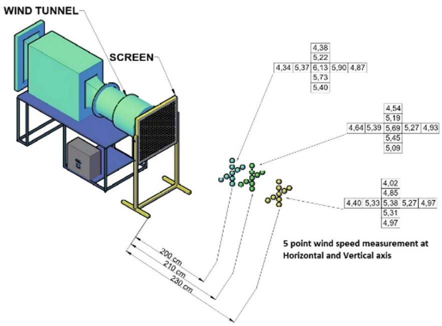

Fig. 4. The uniformity conducted at 5 points horizontally and vertical at 200–250 cm in front of the exhaust tunnel.

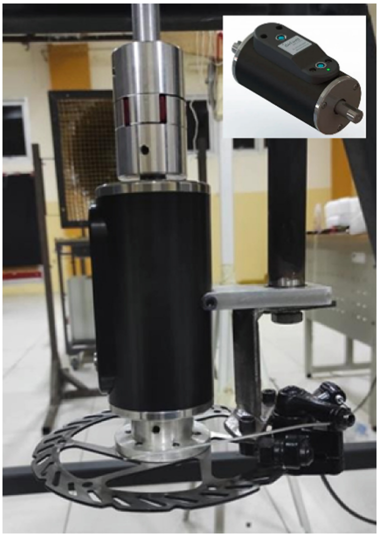

Fig. 5. The M425 torque transducers installed at the end shaft of the turbine integrated with friction brake for mechanical power measurements.

Figure 5 presents the M425 rotary torque sensor used in this experiment. This sensor gives a high precision of 0.1%, torque accuracy range from 0–10 Nm, and sample rate selectable from 1sps–4000 sps as standard. In addition, the Torque Sensor utilized a built-in display Interface Module, providing harvest data for a moment (Nm), power (rpm), and power (Watt).

2.2 Data Reduction

The Savonius shaft power is calculated by measuring the mechanical moment and rotational per minute (rpm) at Reynolds number $Re = 1.03 \times 10^4$. The Reynolds Number depends on freestream velocity V and the diameter of the Savonius turbine and is defined by the following Equation:

$$\frac{\rho VL}{\mu} = \frac{\rho V(2D - e)}{\mu} \tag{1}$$

L is the turbine's length characteristic, D is blade diameter, and e is the overlap distance (m). Furthermore, ρ is the mass of air per unit volume (kg/m^3), μ is a viscosity dynamic (kg/m.s), and V is wind velocity (m/s). Finally, the mechanical power is one of the sensor outputs and can be quantified based on the following Equation:

$$P_m = T\omega \tag{2}$$

where T is a mechanical moment (N.m), then ω is the angular velocity (rad/s). If N refers to the shaft rotation per minute (rpm), it can be obtained by the following formula:

$$\omega = \frac{2\pi N}{60} \tag{3}$$

The tip-speed ratio λ depends on the turbine's angular velocity, and it can be solved with the following Equation:

$$\lambda = \frac{\omega D}{2V} \tag{4}$$

The swept area A defines as the turbine diameter times the height of the turbine and used for calculating the torque coefficient in the following Equation:

$$C_m = \frac{T}{\frac{1}{4}\rho ADV^2} \tag{5}$$

The Savonius turbine efficiency is expressed in the power coefficient C_p and can be found from the Equation below:

$$C_p = \frac{P_m}{P_w} \tag{6}$$

The wind potential power P_w as mentioned in Eq. (6) determined based on Eq. (7).

$$P_w = \frac{1}{2}\rho AV^3 \tag{7}$$

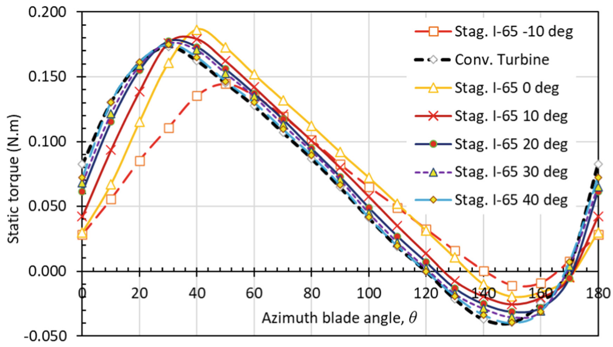

Fig. 6. The growth of static moment (*N.m*) as a function of azimuth blade angle (θ), $Re = 10.3 \times 10^4$, conform between conventional and staggered I-65° cylinder Savonius Turbine $-10° \leq \alpha \leq 40°$.

3 Result and Discussion

3.1 Self-starting Capabilities

The self-starting capabilities of Vertical Axis Wind turbines are an essential deliberation to define the turbine potential starting characteristics rotate without external device assistance. Further evaluation of the turbine static moment at several azimuth angles (θ) has been determined by the M425 torque sensor experimentally. Figure 6 shows the non-dynamic moment aligned between conventional and staggered I-65° Savonius turbine $-10° \leq \alpha \leq 40°$ at specific Reynolds number $Re = 10.3 \times 10^4$. The azimuth angle is only plotted up to 180 degrees because of its periodicity.

The maximum static moment obtained at staggered angle $\alpha = 0°$ at $\theta = 40°$ reaches the value 0.19 N.m. This is because the static moment gradually gets closer to the conventional turbine line as the staggered angle increases to an angle of $\alpha = 40°$. This means that increasing the positive staggered angle gives no improvement in turbine starting capabilities. On the contrary, the negative static moment area reduced significantly at a staggered angle $\alpha = -10°$ indicates the turbine starting capabilities improved. However, this harmful staggering angle $\alpha = -10°$ disturbs an advancing blade airflow, leaving the value at 0.145 N.m maximum, as seen in the graph.

3.2 Power and Torque Coefficient

Figure 7 shows the output experimental investigation on the power coefficient *Cp* against the tip-speed ratio, λ. The staggered I-65° cylinder type at the range $-10° \leq \alpha \leq 40°$ upstream convex blade gives a slight increment on *Cp*. The staggered angle $\alpha = 40°$ reaches maximum $Cp = 0.19$ at tip-speed ratio $\lambda = 0.8$, or 12% higher than a conventional turbine. The negative staggered angle $\alpha = -10°$ reaches maximum $Cp = 0.156$ at tip-speed ratio $\lambda = 0.8$, or 7% below conventional turbine. The maximum TSR increases directly to the staggering angle $-10° \leq \alpha \leq 40°$. Finally, installing an I-65° cylinder type upstream convex blade has proven to jack up the turbine power coefficient *Cp*.

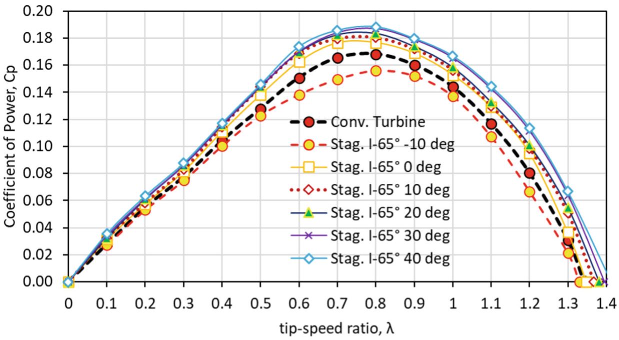

Fig. 7. The growth of turbine *Cp* as a function of tip-speed ratio, λ, compared between the standard turbine and staggered I-65° turbine Savonius at $Re = 10.3 \times 10^4$.

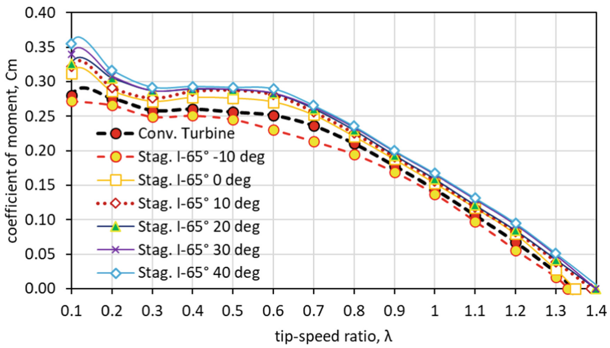

Fig. 8. The growth of turbine torque coefficient as a function of TSR, λ, at $Re = 1.03 \times 10^4$ aligned between the conventional and staggered I-65° Savonius Turbine.

Figure 8 also presents a similar trend based on the *Cm* torque coefficient in line with the *Cp* power coefficient. The *Cm* growth is directly proportional to installing an I-65° cylinder type upstream convex blade. The staggered angle $\alpha = -10°$ indicated below the conventional turbine, and the staggering angle $\alpha = 40°$ seem higher than other lines. The more the staggering angle is given to the turbine configuration, the higher the *Cm*. This consideration proved and enhanced previous hypotheses that installing an I-65° cylinder type positively affects the Savonius wind turbine performance.

The analyzed turbine performance is based on the power and moment coefficients, as summarized in Fig. 9. The graph presents the power coefficient maximum Cp_{max} reached by every single staggered angle compared to the conventional turbine maximum $Cp0_{max}$. Figure 9 also shows the staggering angle $\alpha = 40°$ resulting in the *Cp,* which is 1.12 times higher than a conventional turbine. The staggering $\alpha = 0°$ configuration has a lower effect than another angle, only 1.05 times higher than the standard turbine. The negative staggering angle $\alpha = -10°$ gives a contraindicative 0.95 times lower than a standard turbine.

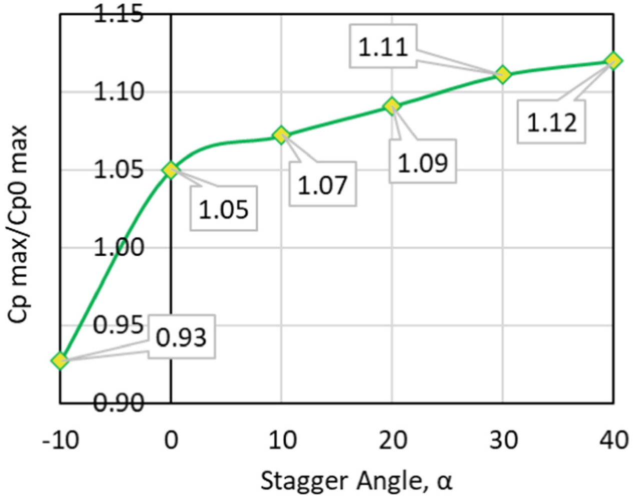

Fig. 9. The development of $Cp_{max}/Cp0_{max}$ as a function of cylinder I-65 staggered angle $-10° \leq \alpha \leq 40°$.

4 Conclusions

The Savonius wind turbine arrangement with the integration of I-65° cylinders type staggered upstream convex blade is investigated experimentally. The investigation was performed based on the dynamic torque coefficient, the power coefficient, and the static moment consideration. The outcome indicated that the I-65° significantly strengthened the turbine efficiency to 12% higher than the turbine standard. Furthermore, the optimum configuration achieved within a staggered angle $\alpha = 40°$ at TSR $\lambda = 0.8$, Reynolds number $Re = 10.3 \times 10^4$ corresponds to wind velocity $V = 5$ m/s.

The starting capabilities of this turbine configuration were investigated under static torque coefficient considerations. The result shows that the static torque reaches a maximum at a staggering angle $\alpha = 0°$ azimuth blade angle $\theta = 40°$. The lower the staggering angle, the more negative torque area disappears, which means a rise in starting capability opposite to the static torque decreases.

According to the current investigation result, it still needs deep analysis and another research area to reveal the optimum staggered angle. However, these predicted flow characteristics could explain the behavior surrounding the turbine and need to be investigated numerically. The last important thing is revealing why static torque is inversely proportional to the staggering angle.

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References

1. P. Javier and G. Montero, "Experimental Study of Flow Through a Savonius Wind Turbine." Accessed: Oct. 07, 2022. [Online]. Available: https://upcommons.upc.edu/bitstream/handle/2117/99258/REPORT_45.pdf
2. H. A. Hassan Saeed, A. M. Nagib Elmekawy, and S. Z. Kassab, "Numerical study of improving Savonius turbine power coefficient by various blade shapes," *Alexandria Engineering Journal*, vol. 58, no. 2, pp. 429–441, Jun. 2019. https://doi.org/10.1016/j.aej.2019.03.005.
3. P. A. Setiawan, T. Yuwono, and W. A. Widodo, "Numerical simulation on the improvement of a Savonius vertical axis water turbine performance to advancing blade side with a circular cylinder diameter variation," *IOP Conf Ser Earth Environ Sci*, vol. 200, p. 012029, 2018, https://doi.org/10.1088/1755-1315/200/1/012029.
4. G. Sakti, T. Yuwono, and W. A. Widodo, "Experimental and numerical investigation of I-65-type cylinder effect on the Savonius wind turbine performance," *International Journal of Mechanical and Mechatronics Engineering*, vol. 19, no. 5, pp. 115–125, 2019.
5. D. M. Prabowoputra, A. R. Prabowo, S. Hadi, and J. M. Sohn, "Assessment of turbine stages and blade numbers on modified 3D Savonius hydrokinetic, turbine performance using CFD analysis," *Multidiscipline Modeling in Materials and Structures*, vol. 17, no. 1, pp. 253–272, 2020, https://doi.org/10.1108/MMMS-12-2019-0224.
6. B. Elhadji Alpha, S. Lakshmi N., and J. Jechiel I., "An Assessment of Computational Fluid Dynamics and Semi-empirical approaches for Vertical Axis Wind Turbine Analysis," 2015. https://doi.org/10.2991/iea-15.2015.29.
7. I. Marinić-Kragić, D. Vučina, and Z. Milas, "Computational analysis of Savonius wind turbine modifications including novel scoop let-based design attained via smart numerical optimization," *J Clean Prod*, vol. 262, p. 121310, 2020, https://doi.org/10.1016/j.jclepro.2020.121310.
8. S. Aiba and H. Watanabe, "Flow Characteristics of a Bluff Body Cut From a Circular Cylinder," *J Fluids Eng*, vol. 119, no. 2, pp. 453–454, 1997, https://doi.org/10.1115/1.2819155.
9. Y. Triyogi, D. Suprayogi, and E. Spirda, "Reducing the drag on a circular cylinder by the upstream installation of an I-type bluff body as passive control," *Proc Inst Mech Eng C J Mech Eng Sci*, vol. 223, no. 10, pp. 2291–2296, 2009, https://doi.org/10.1243/09544062JMES1543.
10. N. H. Mahmoud, A. A. El-Haroun, E. Wahba, and M. H. Nasef, "An experimental study on improvement of Savonius rotor performance," *Alexandria Engineering Journal*, vol. 51, no. 1, Mar. 2012, https://doi.org/10.1016/j.aej.2012.07.003.