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# Effect of Width and Height Ratio of Additional Savonius Blades on Darrieus' Vertical Axis Wind Turbine on Self-Ability Starting and Number of Turbine Revolutions

**Yudi Maulana[1], Bukhari Manshoor[2,*], Izzuddin Zaman[2], Djamal Hissein Didane[2], Kamarul-Azhar Kamarudin[2], Mithun Mondal[3]**

[1] Fakultas Teknik and MIPA,
Universitas Pamulang, Tangerang Selatan, Banten, INDONESIA
[2] Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor, MALAYSIA
[3] School of Engineering of Barcelona
Universitat Politècnica de Catalunya | UPC · ETSEIB, SPAIN

*Corresponding Author

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**Abstract:** The disadvantage of the Darrieus Troposkein Vertical Axis Wind Turbine (VAWT) is that it is not self-powered starting at low wind speed. Another type of VAWT capable of self-starting at low wind speed is the Savonius type. This research discusses the influence of the width and height ratio of Savonius blades in addition to the VAWT Darrieus troponin rotor on the self-starting capability and number of turbine rotations. The method used is an experiment with additional Savonius blade design variations in the width ratio and rotor heights of 0.718, 0.738 and 0.758. Each has the same swept cross-sectional area of 0.04 m$^2$, which is installed under the VAWT Darrieus symmetric troponin rotor, which has an area of the swept cross-section of 0.04 m$^2$ and tested at a wind speed of 2 m/s to obtain a time response self-starting and several turbine rotations. Test data was analysed to determine the effect of variations in width ratio, and the height of the Savonius blade additionally affects the self-starting capability and number of turbine rotations. The resulting ratio between the width and height of the Savonius blade is also 0.738, which can increase the self's capability better, starting at 0.758 and 0.718. The ratio between the width and height of the additional Savonius blade 0.758 can produce more turbine rotations than 0.718 and 0.738.

**Keywords:** Darrieus Troposkein, Vertical Axis Wind Turbine (VAWT), self-starting, Savonius

## 1. Introduction

Based on the geographical conditions of the region islands, the highest monthly wind speed is 1.5 m/s, with a maximum average of 12 m/s, and wind direction frequently changes [1] or not yet the availability of electricity networks in inland areas in Kotabaru regency [2], then there is an opportunity great for the use of wind energy as a power generation source. Axis wind turbine vertical has the highest efficiency as the power plant is Darrieus type Troposkien. But this turbine does not have any drawbacks and is capable of self-starting at low wind speeds. Another type of vertical axis wind turbine capable of self-starting but low efficiency is the Savonius type. Therefore, the Darrieus turbine must be modified by adding a Savonius vane to self-start at low wind speed.

The problem of the research is what size a Savonius vane should be added to the Darrieus turbine rotor for the self-starting capability of the turbine to be increased optimally and how it affects the number of rotations of the turbine rotor. Spoon size is related to the swept surface area and the ratio between the width and height of the additional Savonius vane. The size of a wind turbine is measured in the shape-swept area (swept surface area) or the area-swept surface of rotating turbine blades. The swept surface area for wind turbines on the horizontal axis is calculated using Eqn. 1 [3].

$$S = 0.785\,D2 \qquad (1)$$

**Corresponding author: dosen01302@unpam.ac.id*
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Meanwhile, for vertical axis wind turbines with an aspect ratio (comparison between height and rotor diameter) of 1.5, the area of the swept surface of the wind turbine is calculated using Eqn. 2 [3].

$$S = 1.000\ D2 \qquad (2)$$

where,

$S$: sweep surface area
$D$: rotor diameter

VAWT Darrieus blade shape, in general, uses a symmetrical aerofoil of the NACA type 00XX because it has a high lifting force, good stall characteristics combined with low drag and available performance. Previous rotors used more thin aerofoils, namely types NACA 0012 and NACA 0015. However, the requirements for strength increased, causing some manufacturers to choose NACA 0018 aerofoil [4].

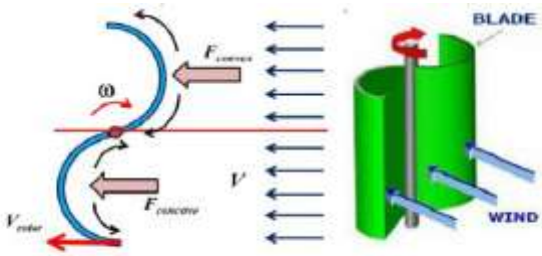


**Fig. 1 - Savonius turbine rotor [4]**

The Savonius turbine swept surface area is shown in Eqn. 3. The ratio between *d/h*, which produces torque and $C_p$ the best, is 0.42 [5]. Research conducted by Wahyudi, B. *et al.* [6] and Ali, S. *et al.* [7] in a way makes variations in the ratio between the gap and the diameter (*e/d*) to increase $C_p$. The value range evaluated for the e/d ratio is 0.1 up to 0.5, and they concluded that performance The optimum is obtained at an e/d ratio of 0.242. Based on experiments conducted by Mohammed Hadi [8], Savonius wind turbines with two more blades are more efficient than three-blade Savonius wind turbines because they have a higher power coefficient [9,10].

$$A = h(2d\text{-}e) = h\ xD,\ (m^2) \qquad (3)$$

Studies conducted by W. Roynarin [11] stated that the Savonius rotor two-tier is superior in slenderness compared to one stacking and addition plate plates at the bottom, intermediate, and end ends over the Savonius rotor adds rotor performance if compared to a rotor without a disc at each end of the rotor. Sarma, J. *et al.* [12] have released a wind turbine patent Savonius-Darrieus hybrid that achieved $C_p$ is around 30% higher at a tip speed ratio (*TSR*) of around 2.

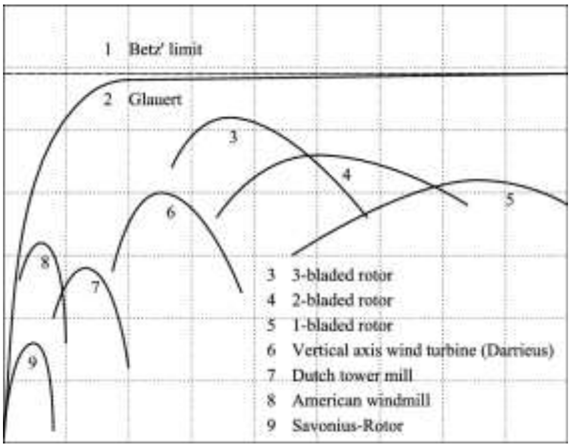


**Fig. 2 - $C_p$, according to the TSR, for the most common wind turbines [13]**

This means the work speed is higher than just the Savonius rotor alone. Wakui, T. et al. [14] tested the performance of a combined Savonius-Darrieus machine. Turbine Darrieus (three-bladed rotor radius, $R$ = 0.375 m, and height, $H$ = 0.75 m) combined with three different Savonius models (half circle, $b/c$ = 0.0, $b/c$ = 0.25, and Bach model) and obtained results.

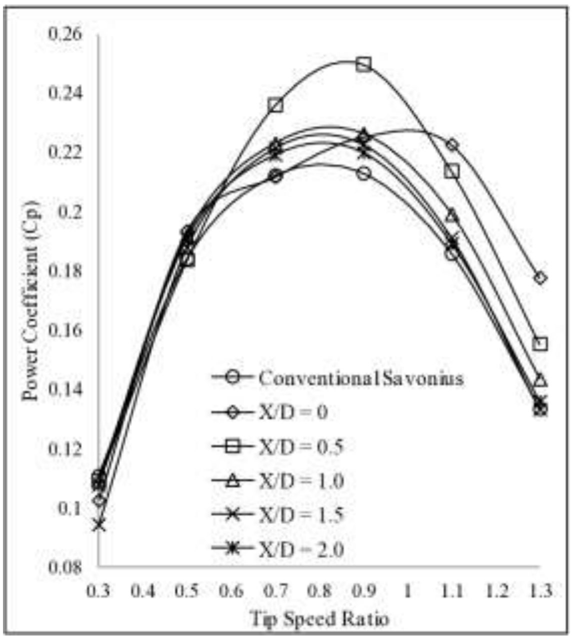


**Fig. 3 – Comparison of performance of the Savonius turbine for power coefficient with changes in horizontal distance [13]**

The performance of the Savonius turbine for power coefficient ($C_p$) with changes of horizontal distance (*X/D*) of 0.0, 0.5, 1.0, 1.5 and 2.0 are shown in Figure 3. The figure shows the reflection performance of the Savonius turbine, which includes the value of the power coefficient as the function of the tip speed ratio (TSR). It is clear that installing a circular cylinder beside the advancing blade [13]

Based on theoretical modelling, intent and success in scaling up self-starting capability can be evaluated. It is difficult to determine the effect of aspect ratio on self-starting capability. But with the number of turbine blades increasing, the effect can be seen as an apparent increase in the ability for self-starting. But if the number of blades is more than four, turbines become unfit, and several factors, such as power performance, economy, rotor inertia, etc., need to be considered. However, high solidity and Reynolds number increasing self-starting, economic factors must be considered. Additionally, the profile of a thick blade significantly affects a significant increase in self-starting [15]. The greater the number of rotations, the more the output power of the turbine will increase if it has constant torque.

## 2. Methodology

The research design was carried out using an experimental method. Experimental data is processed to determine its optimal effect on improving self-starting ability and the number of turbine revolutions. Figure 4 shows the model used in the experimental work, with the geometric parameter shown in Table 1. The methodology process is summarised in the flow chart in Figure 5.

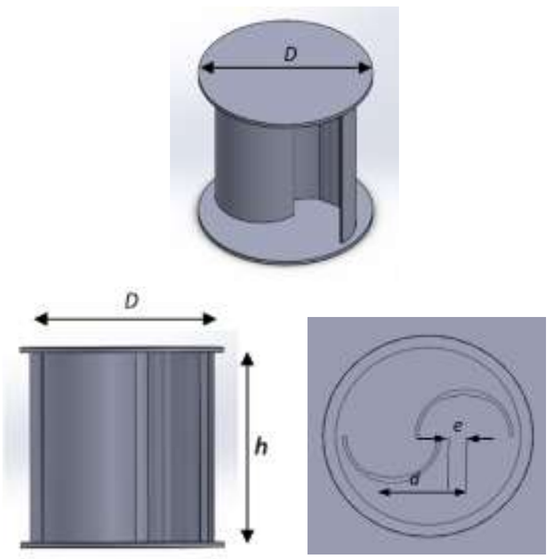


**Fig. 4 - Model of Savonius vertical axis wind turbine**

**Table 1 – Geometric parameter for the Savonius turbine**

| Design | Darrieus rotor sweep surface area ($m^2$) | Ratio of width and height of the Savonius blade, $D_s/h_s$ |
|---|---|---|
| 1 | 0.04 | 0.718 |
| 2 | 0.04 | 0.738 |
| 3 | 0.04 | 0.758 |

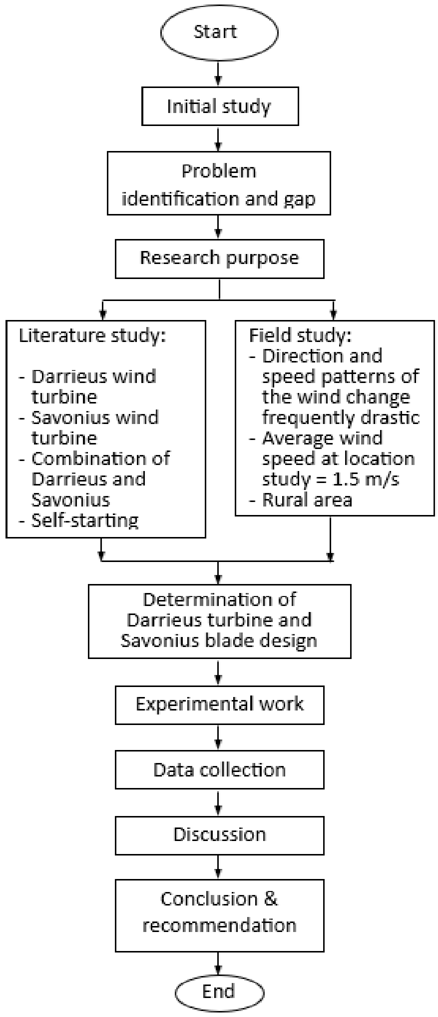


**Fig. 5 – Flow chart of the process work**

For the determination of the Darrieus turbine and Savonius blade design, as indicated from the chart, the results are as follows.

1. Prototype VAWT Darrieus symmetric troposkein
   a. Darrieus NACA 0018 airfoil shape.
   b. Number of Darrieus blades, $N$ = 2
   c. Darrieus rotor Aspect Ratio, $AR$ = 1.5
   d. Swept surface area of the Darrieus Rotor, $AD$ = 0.04 m$^2$.
   e. Darrieus Blade Chord Length, $c$ = 0.05 m.

2. Three additional Savonius vane shapes
   a. Additional Savonius turbine area, $A_s$ = 0.04 m$^2$
   b. The ratio between the width and height of the Savonius blade, $D_s/h_s$, 0.718, 0.738, and 0.758.
   c. The ratio between the gap and the diameter of the Savonius blade = 0.242.
d. Number of Savonius blades, $N$ = 2.
e. Savonius airfoil shape = Semicircle.
f. Number of Savonius rotor levels = 2 levels.

3. Savonius has a diameter of 0.1968 m.


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## 3. Results and Discussion

Data from the Darrieus rotor experiment Troposkien before adding the spoon and after adding variations in blade shape Savonius obtained response time data for self-starting on each rotor as in Table 2 and Table 3.

**Table 2 - An example of a table**

| Exp. | Darrieus rotor sweep surface area ($m^2$) | Self-starting response: *R* = Shut-up *S* = Self-starting | Time required for self-starting (second) |
|---|---|---|---|
| 1 | 0.04 | *R* | - |
| 2 | 0.04 | *R* | - |
| 3 | 0.04 | *R* | - |

**Table 3 - An example of a table**

| Exp. | Darrieus rotor sweep surface area ($m^2$) | Self-starting response: *R* = Shut-up *S* = Self-starting | No. of rev. of the combined turbine rotor (rpm) |
|---|---|---|---|
| 1 | 0.04 | *R* | - |
| 2 | 0.04 | *R* | - |
| 3 | 0.04 | *R* | - |

Based on experimental data first in Table 2 and Table 3, it can be seen that the Darrieus wind turbine is troposkien symmetric, incapable of self-starting at a wind speed of 2 m/s, and has a zero number of rotations.

**Table 4 - An example of a table**

| Exp. | Sweep surface area ($m^2$) | Savonius rotor width and height ratio ($D_s/h_s$) | Response: *R* = Shut-up *S* = Self-starting | Time required (Second) |
|---|---|---|---|---|
| 1 | 0.04 | 0.718 | *S* | 3.35 |
| 2 | 0.04 | 0.738 | *S* | 2.83 |
| 3 | 0.04 | 0.758 | *S* | 2.88 |

**Table 5 - An example of a table**

| Exp. | Sweep surface area ($m^2$) | Savonius rotor width and height ratio ($D_s/h_s$) | Response: *R* = Shut-up *S* = Self-starting | *RPM* |
|---|---|---|---|---|
| 1 | 0.04 | 0.718 | *S* | 198 |
| 2 | 0.04 | 0.738 | *S* | 174 |
| 3 | 0.04 | 0.758 | *S* | 200 |

Based on experimental data in Table 4, the Darrieus wind turbine symmetrical troposkein with the addition of a spoon Savonius semicircle, which has an area swept cross-section 0.04 $m^2$ and width ratio and rotor height 0.738, capable of self-starting at a wind speed of 2 m/s with response time The fastest 2.83s starts rotating after the door the wind tunnel opened. Based on experimental data in Table 5, the Darrieus wind turbine symmetrical troponin with the addition of a spoon Savonius semicircle, which has an area swept cross-section of 0.04 m2 and width ratio and blade height of 0.758 at a wind speed of 2 m/s produces the largest rotation of 200 rpm.

## 4. Conclusion

Based on research results and discussion then, the following conclusions are obtained:

1. The ratio of the width and height of the Savonius blade added to influence Darrieus turbine self-starting capability. The ratio between widths and an additional Savonius rotor blade height of 0.738 can increase the self-starting ability of Darrieus rotor with the fastest response time of 2.83 s better than the ratio between width and height of Savonius rotor blades additional 0.758 and 0.718.
2. Optimal additional Savonius vane is obtained with a swept surface area of 0.04 m2 with the ratio between the width and height of the Savonius rotor additional 0.758, in wind speed conditions 2 m/s can produce several rotations turbine 200 rpm.


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