The role of the blades number and pitch angles to the capability of self-start the Darrieus wind turbine

S Adiwidodo*, E Yudiyanto, B Wahyudi and S H Susilo

Department of Mechanical Engineering, State Polytechnic of Malang, Jl. Soekarno-Hatta No. 9, Malang 65141, Indonesia

*satwo.ro.adiwidodo@polinema.ac.id

Abstract. Darrieus is classified as a vertical axis wind turbine that has a simple construction. It is widely used for small-scale domestic needs in rural or aquaculture areas. As with other types of vertical axis wind turbines, Darrieus have low efficiency. There is resistance on one side of the blade which aggravates the shaft rotation. Another problem is the low ability to self-starting. Some even need help from an external source to start. This is certainly detrimental in terms of energy conversion. The purpose of this study is to obtain information on the wind speed needed for a Darrieus to self-starting on variations in the number of blades and pitch angles. The blade profile used is NACA 6412. Variations in the number of blades are 2, 3, 4 and 5 and pitch angles of -10°, -5°, 0°, 5°, and 10°. Data retrieval was carried out experimentally using the wind tunnel. It is shown that the self-start wind speed was strongly influenced by the number of turbine blades. The number of blades 5 requires the lowest average self-start wind speed. The pitch angle has a different effect on the wind self-starting speed depending on the number of blades.

1. Introduction

The energy that is widely used today comes from very limited fossil fuel. Various studies have been conducted to utilize renewable energy. One of the renewable energies that are being researched at this time is wind energy. As with the horizontal axis wind turbine, there have been many developments in the vertical axis wind turbine [1,2]. The most widely applied and researched vertical axis wind turbine is the Darrieus type.

As with other types of vertical axis wind turbine (VAWT), Darrieus usually have low efficiency when compared to horizontal axis wind turbines, however, this type of turbine has the advantage of being able to receive fluid flow from all directions. The low efficiency of VAWT caused by the wind flow in the turbine is split into two sides. One side of the blade is hindering the other side of the turbine blades. There are several studies to improve the performance of the Darrieus wind turbine. Among them by changing the pitch angle [3-5]. It has been designed pitch-controlled H-Darrieus VAWT with asymmetric NACA 0021 airfoil for maximum lift drag ratio [3]. The numerical simulation shows that the pitch angle has a significant effect on the aerodynamic characteristics of the wind turbine. The airfoil used is NACA0021 with the number of blades 2. The simulation results show that the maximum pressure difference on the blade surface was obtained at the blade pitch angle of $\beta = 6^\circ$ in the upstream region. However, the maximum pressure coefficient was shown at the blade pitch angle of $\beta = 8^\circ$ in the downstream region. The torque coefficient acting on a single blade reached its maximum value at the blade pitch angle of $\beta = 6^\circ$ [4]. The simulation of the effect of blade pitch angle on the aerodynamic
performance of the NACA 63415 H-Darrieus VAWT blade at a low wind speed of 6 m/s shows a positive pitch angle of +5° improves turbine performance in the upwind position, while a negative pitch angle of -5° increases the performance of the turbine in the upwind position. downwind which reduces wake [5].

Another problem with the Darrieus wind turbine is its low ability to self-starting. Some even need an external source to start. Several studies have been conducted to solve this problem. The simulation of NACA 0012 shown that a lightly loaded, three-bladed rotor always has the potential to self start under steady wind conditions, whereas the starting of a two-bladed device is dependent upon its initial starting orientation [6]. It has been investigated a numerical model is used to simulate the starting of an H-rotor Darrieus turbine under steady wind conditions demonstrating that modeling remains constrained by the quality of data on aerofoil characteristics [7]. An innovative blade profile design for Darrieus VAWT is presented and named EN0005, offering the ability to self-start without the need for extra components or external electricity feed-in and without compromising a good performance at high TSR [8].

Mathematical modeling has been investigated to control the angle of attack of the blade profile, which allows a self-start to wind speeds as low as possible is presented for the straight blade of Darrieus turbine [9]. Systematic synthesis on the self-starting aerodynamic characteristics of vertical axis wind turbines based on the numerical analysis shows that the solidity and fixed pitch angle influence the aerodynamic characteristics with \( \beta = -2.5° \) has better self-starting aerodynamic characteristics [10]. A 2D numerical model base it is found that the incident flow velocity and the moment of inertia of the rotor have little effect on the averaged values of tip-speed ratios in the equilibrium stage under no-load conditions. In the system load calculations, four modes of self-starting were found: stable equilibrium mode, unstable equilibrium mode, switch mode and halt mode [11]. A numerical method was developed and validated to accurately simulate the interaction between the wind and VAWT indicated that the VAWT with S-1046 blade had a better overall performance as compared to the one with the NACA0018 blade, where the reduced self-starting time [12].

From previous research, it is known that changes in pitch angle greatly affect the aerodynamic characteristics and performance of the Darrieus wind turbine. Changes in the ability of self-star are rarely discussed concerning changes in pitch angle. This research was conducted experimentally using asymmetric airfoils with variations in the number of blades and pitch angle. The purpose of this study is to obtain information on changes in the self-starting wind speed of the Darrieus wind turbine on variations in blade number and blade pitch angle.

2. Material and methods

The effect of the number of blades and the pitch angle on the Darrieus wind turbine was carried out experimentally. The wind turbine prototype has a rotor diameter of 1 m with an airfoil span of 1 m. The blade profile used is an asymmetrical airfoil NACA 6412 (Figure 1).

Figure 1. Darrieus wind turbine (a) airfoil NACA 6412; (b) prototype complete design.
Variations in the number of blades are 2, 3, 4 and 5 and pitch angles of $\beta = -10^\circ$, $-5^\circ$, $0^\circ$, $5^\circ$, and $10^\circ$ (Figure 2). Data retrieval was carried out experimentally using the wind tunnel. At initial orientation, there is a blade radius in the direction of the flow of wind on the front side. The wind speed in the control from zero is increased slowly until the turbine starts moving. When the turbine starts moving, the wind speed is recorded as the turbine's self-starting speed. Fan motor speed control with variable speed drive. Wind speed measurement is done using a portable digital anemometer. Data were recorded and plotted using Excel.

3. Results and discussion

3.1. Effect of blade number to self-starting wind speed

The number of blades is very influential on the wind speed needed to have self-starting as shown in Figure 3. The fewer number of blades, the higher the wind speed needed to have self-starting, conversely the greater number of blades the lower the wind speed needed to do self-starting. It can be understood that the greater the number of blades, the more wind energy can be converted to torque. The number of blades will increase the area that receives wind energy. Figure 3 shows the blade number 5 has an average low self-starting speed at all pitch angles. The pitch angle affects the tendency of self-starting wind turbine speed. At zero-degree pitch angle, self-starting speed occurs with a linear tendency towards the number of blades. Meanwhile, the minus or positive angle tends to change in the polynomial of the blade count. For the negative pitch angle, the change in velocity tends to decrease as the number of blades increases, until the number of blades 4 reaches the lowest speed then rises. Conversely, for a
positive pitch angle, there is a tendency to rise at low amounts to 3, then drop to the lowest speed at 4.17 m/s at the pitch angle of $\beta = 10^\circ$ with the number of blades 5.

**Figure 3.** Wind self-starting speed with various number of blade.

**Figure 4.** Force vector (unscale) for various number of blade.

Figure 4 shows the force vector works on the airfoil blade. Increasing the number of blades increases the area that can convert wind energy. The addition of the force vector to the turbine blade increases the torque required by the turbine to rotate so that the number of blades 5 has a lower self-starting wind speed.

### 3.2. Effect of pitch angle to self-starting wind speed

Figure 5 shows that for the number of blades 2 and 5, the change in pitch angle from negative to positive values reduces the self-starting wind speed, while the number of blades 3 and 4 shows the opposite trend. The turbine with the number of blades 2 achieves the lowest self-starting wind speed at a pitch angle of $\beta = 5^\circ$, the number of blades 3 at a pitch angle of $\beta = -5^\circ$, the number of blades 4 with a pitch angle of $\beta = -10^\circ$, and the number of blades 5 at a pitch angle of $\beta = 10^\circ$. 
Figure 5. Wind self-starting speed with various pitch angle.

Figure 6 shows the number of blades 5 with a pitch angle of $\beta = 10^\circ$ which increase the airfoil's angle of attack. The angle of attack is the angle formed by the chord line with the relative wind. There is an additional angle of attack on the main blade on the downwind section. Increasing the angle of attack increases the lift produced. The increase in lift is of course accompanied by an increase in drag, but the ratio between lift and drag is still high, giving additional torque to the turbine shaft. That is why at low wind speeds the turbine is capable of self-starting. These results confirm the simulation study [4] for the type of symmetrical NACA optimum pitch angle $\beta = 6^\circ$-$8^\circ$. At higher pitch angles, the airfoil has a large angle of attack which can cause a stall, which is counterproductive to the performance of wind turbines. This research was conducted on one type of asymmetrical airfoil (NACA 6412). Future work was to compare the self-starting performance of various forms of NACA, both symmetrical and asymmetrical types.
4. Conclusions
From the results experiment of a Darrieus wind turbine with a various number of blade and pitch can be concluded as follows:

- It is shown that the self-start wind speed was strongly influenced by the number of turbine blades. The number of blades 5 requires the lowest average self-start wind speed.
- The pitch angle has a different effect on the wind self-starting speed depending on the number of blades.

Acknowledgment
This research was supported by the Applied Research Fund of DIPA State Polytechnic of Malang Number: SP DIPA-023.18.2.677606/2020. This research is a collaboration with students in completing their final projects. Thanks to Ade Yafi Reyhan, Bagas Mahardika, Jauhari Ulfi, M. Ilham Wildani, and M. Rizky Fadillah who helped prepare the prototype and retrieve the data.

References
[1] Möllerström E, Gipe P, Beurskens J, and Ottermo F 2019 A Historical Review of Vertical Axis Wind Turbines Rated 100 KW and Above Renewable and Sustainable Energy Reviews 105 (2019) 1-13
[2] Adiwidodo S, Wahyudi B, Yudiyanto E, Subagiyo S, Hartono M, and Baananto F 2020 Simulation Study of Savonius Tandem Blade Wind Turbine Using an Adjustable Deflector IOP Conference Series: Materials Science and Engineering 732 (1)
[3] Mauri M, Bayati I, and Belloli M 2014 Design and Realisation of a High-Performance Active Pitch-Controlled H-Darrieus VAWT for Urban Installations In 3rd Renewable Power Generation Conference
[4] Yang Y, Guo Z, Song Q, Zhang Y, and Li Q 2018 Effect of Blade Pitch Angle on the Aerodynamic Characteristics of a Straight-Bladed Vertical Axis Wind Turbine Based on Experiments and Simulations Energies 11(6)
[5] Mazrarbhuiya H M S M, Biswas A, and Sharma K K 2020 Low Wind Speed Aerodynamics of Asymmetric Blade H-Darrieus Wind Turbine-Its Desired Blade Pitch for Performance Improvement in the Built Environment Journal of the Brazilian Society of Mechanical Sciences and Engineering 42(6)
[6] Dominy R G, Lunt P, Bickerdyke A, and Dominy J 2007 Self-Starting Capability of a Darrieus Turbine Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy 221(1) 111-210
[7] Hill N, Dominy R, Ingram G, and Dominy J 2009 Darrieus Turbines: The Physics of Self-Starting Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy 223(1) 21-29
[8] Batista N C, Melício R, Mendes V M F, Calderón M, and Ramiro A 2015 On a Self-Start Darrieus Wind Turbine: Blade Design and Field Tests Renewable and Sustainable Energy Reviews 5 508-522
[9] Douak M and Aouachria Z 2015 Starting Torque Study of Darrieus Wind Turbine International Journal of Mathematical, Computational, Physical, Electrical, and Computer Engineering 9(8) 472-477
[10] Zhu J, Huang H, and Shen H 2015 Self-Starting Aerodynamics Analysis of Vertical Axis Wind Turbine Advances in Mechanical Engineering 7(12) 1-12
[11] Liu Z, Qu H, and Shi H 2016 Numerical Study on Self-Starting Performance of Darrieus Vertical Axis Turbine for Tidal Stream Energy Conversion Energies 9(10)
[12] Sun X, Zhu J, Hanif A, Li Z, and Sun G 2020 Effects of Blade Shape and Its Corresponding Moment of Inertia on Self-Starting and Power Extraction Performance of the Novel Bowl-Shaped Floating Straight-Bladed Vertical Axis Wind Turbine Sustainable Energy Technologies and Assessments 38(2020) 100648