

PAPER • OPEN ACCESS

Performance testing of Darrieus turbine in hydrokinetic power plant model

To cite this article: R Permatasari *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **737** 012009

View the [article online](#) for updates and enhancements.

You may also like

- [Experimental Study Influence of High Fin on Naca Airfoil 0018 On Performance Of H-Type Darrieus Wind Turbine](#)
Emie Santoso, Ikhtiar Syah Awika and Nopem Ariwiyono
- [Design and performance optimization of a combined darrieus-savonius turbine with DTBO alqorithm in low wind speed regime](#)
S Gupta, A Biswas, T Malakar et al.
- [Impact of Aerofoil Shapes on the Performance of Darrieus Vertical Axis Turbines: A Computational Study for Offshore Wind and Hydro Applications](#)
Shubham Sharma, Shivam Singh Tomar and Anupam Dewan

Performance testing of Darrieus turbine in hydrokinetic power plant model

R Permatasari*, L F Hidayat and F M Permana

Department of Mechanical Engineering, Faculty of Industrial Technology, Universitas Trisakti, Jakarta, Indonesia

*rosyida@trisakti.ac.id

Abstract. Darrieus Turbine is a type of vertical axis hydrokinetic turbine that is often used in hydroelectric power plant. This research aims to performance test of Darrieus Water Turbine in hydro power plant experimentally. Darrieus Turbines uses blades with type NACA 0018 and Polylactic Acid material. In performance test of the Darrieus Turbine, 5 variations of fluid flow velocity are: 0.77 m/s, 0.89 m/s, 0.99 m/s, 1.17 m/s, and 1.25 m/s are used. Also the test uses variations in the number of turbine blades are: 2 pieces, 3 pieces and 4 pieces with 0°, 10°, and 15° angle of attack. The test results obtained the highest rotation at 195.17 rpm with a turbine mounted 2 blades and an angle of attack 0°, the power generated at the rotation is 0.18 Watt. But the optimal power was obtained 0.1 Watt for 4 blades turbine, because the turbine could to do self-starting at fluids velocity 0.77 m/s for all angle of attack. The optimum result was produced by 4 blades turbine, because the turbine could do self-start at 0.77 m/s water velocity either at 0°, 10°, or 15°. The optimum power was produced by 4 blade turbine, which was 0.1 Watt.

1. Introduction

With global warming attention have been turning to resources for the advancement of renewable energy technologies. To move away from fossil fuel-based energy sources, humans will be increasingly concerned with the use of various renewable resources. If each country evaluates its resources, it will be recognized that hydrokinetic energy has a significant contributor to its renewable energy portfolio [1-3].

These energies can be utilized to produce electricity by using hydrokinetic turbine. The principle of hydrokinetic turbine in a hydro power plant is to transform potential and kinetic energies contained in water flow into mechanic energy. Water flow that hits the turbine blades cause the turbine rotates and creates movement on the generator to produce electricity. The benefits of hydrokinetic turbine utilization are less requirement on location determination, it requires no dam, low installation cost and time requirements [2,4,5].

Hydrokinetic turbine is generally divided into two categories which are Horizontal Axis Turbine (HAT) and Vertical Axis Turbine (VAT). HAT hydrokinetic turbine is fitted with rotation axis similar as fluid direction meanwhile VAT hydro-kinetic turbine is fitted with rotation axis perpendicular with fluid direction [6]. Darrieus Turbine is one of VAT types which is developed to benefit water flow [7].

This research aims to test performance of Darrieus Turbine using blades with type NACA 0018 using variations of fluid flow velocity (0.77 m/s, 0.89 m/s, 0.99 m/s, 1.17 m/s, 1.25 m/s) and variations of



number blades are: 2 pieces, 3 pieces and 4 pieces with 0° , 10° , and 15° angle of attack [8-10]. The scope of this research is a laboratory scale using existing tool models in Mechanical Engineering Laboratory.

2. Research methodology

In Figure 1, the manufactured prototype design could be seen as follow. The motor boat that was used to produce water flow on fluid vessel which was utilized to spin Darrieus Turbine. NACA 0018 with chord length of 40mm and blade length of 180mm was fabricated by utilizing a 3D printer using PLA (Polylactic Acid) material. NACA 0018 has lift coefficient that will increase in line with the rise of fluids velocity, but it is not same for other types of NACA which the lift coefficient starts to increase in certain Reynolds conditions [11,12].

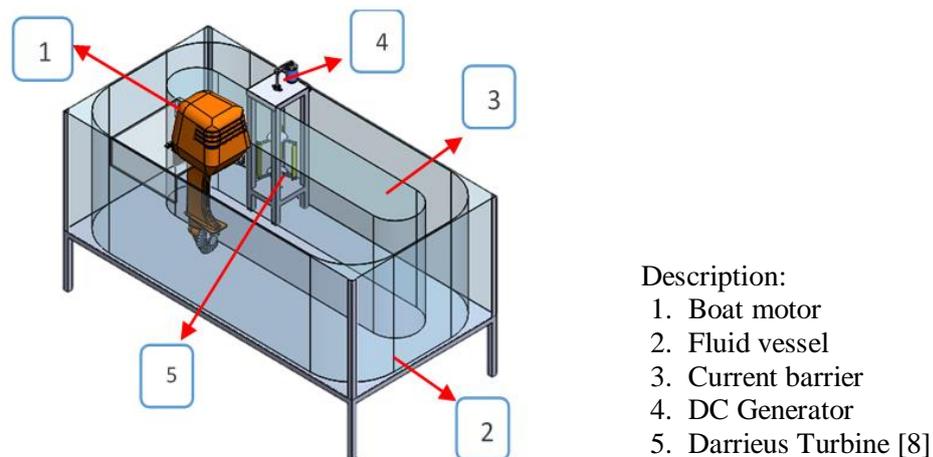


Figure 1. Hydrokinetic power plant modeling.

2.1. Testing procedure

In Hydrokinetic Power Plant testing process, Darrieus Turbine was connected by timing belt to a generator with rotation ratio of 1:2 which means 1 turbine rotation same as 2 generator rotations. The generator was fitted with a 2.5 volt and 0.3 ampere lamp. The collections of turbine rotation data, current and voltage produced by the generator were conducted by measuring turbine rotation (rpm) with a tachometer, electrical current (A) by using ampere meter and voltage (volt) by using volt meter. These data were transformed into power unit (watt) [8].

Data collection was conducted based on a combination of blade number, angle of attack, and fluid flow variations. Measurement was conducted by installing Darrieus Turbine with 2 blades on angle of attack variations of 0° , 10° , and 15° and fluid flow variations (0.77 m/s, 0.89 m/s, 0.99 m/s, 1.17 m/s, 1.25 m/s) and then, the test was continued by the installation of the turbine with 3 blades on angle of attack variations of 0° , 10° , and 15° and fluid flow variations. After that, the test was finished by the installation of the turbine with 4 blades on angle of attack variations of 0° , 10° , and 15° and fluid flow variations. Angle of attack degree measurement was conducted by using a protractor, and in the airfoil bolt a straight line is drawn as Y axis (angle of attack measurement reference). The angle of attack was measured at positive direction away from the turbine shaft as seen in Figure 2.

Blade number variations are used to find turbine lift force and drag force. These forces influence power produced by the turbine. The parameters as the recorded observation object of this research are: water velocity, turbine rotor rotation, generator axis rotation, and generator current and voltage. From these data, total electricity force and efficiency were determined. The power data was produced from current and voltage power generated during testing [5,10].

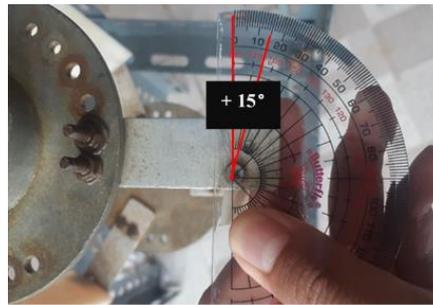


Figure 2. Measurement angle of attach of Darrieus turbine.

3. Results and discussion

To determine type of fluid flow produced in fluid vessel (Laminar, Turbulent and Transition) Reynold number measurement is required. The vessel had wide 0.2m and the water height was 0,48m. The kinematic viscosity of water fluid at 30°C of atmosphere temperature is $0.8 \times 10^{-6} \text{m}^2/\text{s}$. Reynolds number can be measured by using equation 1 and 2 [13]:

$$R = \frac{A}{p} = \frac{by}{b+2y} = \frac{0.22 \times 0.48}{0.22+2(0.48)} = 0.09 \tag{1}$$

$$Re = \frac{vxR}{v} = \frac{0.77 \times 0.09}{0.8 \times 10^{-6}} = 86625 \tag{2}$$

The Reynold number shown that the fluid flow in this system was as turbulent flow.

Testing was conducted by using fluid flow velocity variations with NACA 0018 with angle of attack 0° . Darrieus Turbine measurement result data could be seen in Figure 3 and data on the produced power was shown in Figure 4. The figure shown that the higher velocity gave the higher the rotation produced. At 0° of angle of attack with a speed of 1.25 m/s, the blue line shown that the highest rotation was at 195.17 rpm. The produced electricity was linear with turbine rotation (rpm). The higher the turbine rotation, the higher the power produced. The blue line shown that power produced by Darrieus Turbine with 2 blades is 0.18 watt at the highest. On 3 blades testing, the power produced was higher than 4 blades testing, although the differences were not significant. The rotation produced in 3 blades and 4 blades testing were not continuous, because the turbine stopped to rotate when the fluid hit the turbine blades.

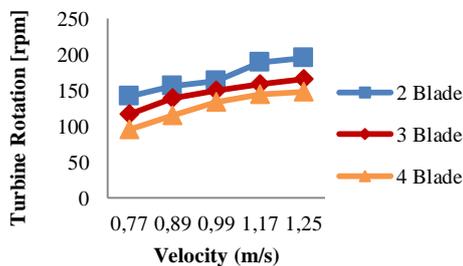


Figure 3. Rotation produced at 0° angle.

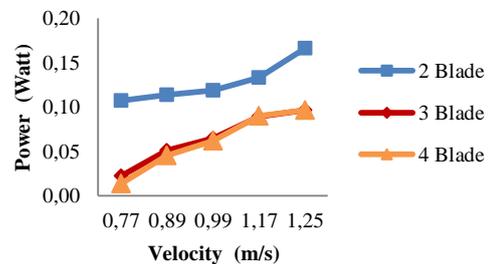


Figure 4. Power generated at 0° angle.

Figure 5 showed results of testing at 10° angle. The graphic showed that at 10° , there was no rotating for the turbine with 2 blades for all fluid flow velocity, because the higher the angle of the attack made the higher drag and diminished lift force. Distance between blades was not too small and the turbine blades were unable to transform fluid current into turbine rotation. From the figure, it could be seen that at 10° produced the best rotation with 3 blades turbine with highest rotation of 160.1 rpm.

Electrical power produced at 10° angle could be seen in Figure 6. Electricity produced was linear to turbine rotation (rpm). The higher the turbine rotation gave the higher the power generated. Orange line represents electricity current produced by the turbine with 3 blades which produced 0.08 watt as the highest level. Testing at 10° angle with 2 turbine blades no electricity was produced because the range between each blades were too small, and turbine blades were unable to distribute fluid velocity into turbine rotation. Because of the turbine was not rotate, there was no power was produced at fluid flow velocity 0.77 m/s-1.25 m/s.

From Figure 7, it showed that at 15° angle and 0.77 m/s of velocity, 3 blades turbine was unable to rotate until the velocity reaches 0.89 m/s. The situation was different with 4 and 5 blades turbine, which could do self-start [14] at low velocity 0.77 m/s. Figure 8 showed the highest power produced was 0.03 Watt that happened at 15° angle and 1.25 m/s velocity.

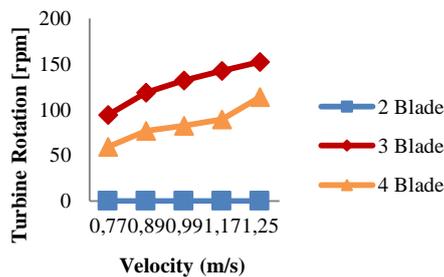


Figure 5. Rotation produced at 10° angle.

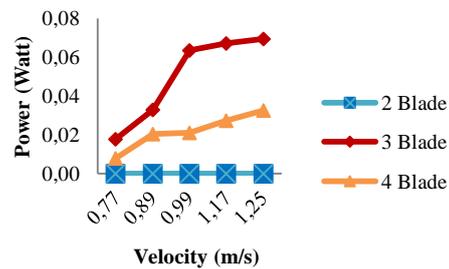


Figure 6. Power generated at 10° angle.

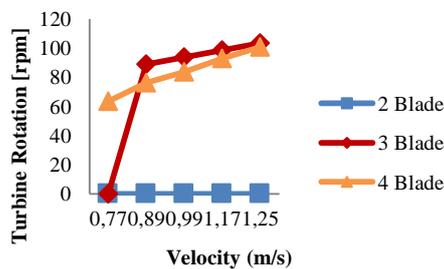


Figure 7. Rotation produced at 15° angle.

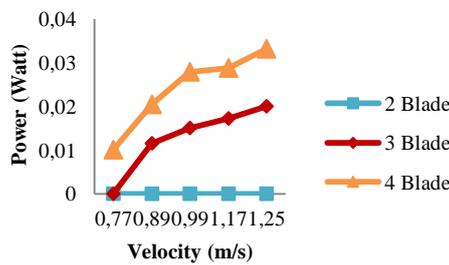


Figure 8. Power generated at 15° angle.

From those results could be explained that the higher of angle of attack gives the lower the turbine rotation [15]. This happened because the higher the angle of attack gives the higher the turbine resistance. The angle of attack at 0° produced better rotation than 10° and 15° angles.

The number of blades were also influencing the drag force. The more blades were installed, the higher the turbine solidity so the rotation tend to be lower if compared with fewer blades. Darrius Turbine with 2 blades at 0° angle of attack produced better rotation than 3 and 4 blades turbines. However, at 10° and 15° angle of attacks, 2 blades turbine were unable to turn on because the turbine failed to extract kinetic energy of the fluid current into turbine rotation energy.

Data produced from hydrokinetic power plant with angle of attack variations (0°, 10°, and 15°) and Darrius turbine number of blades (2, 3 and 4) on turbine rotation produced were showed in Figure 9.

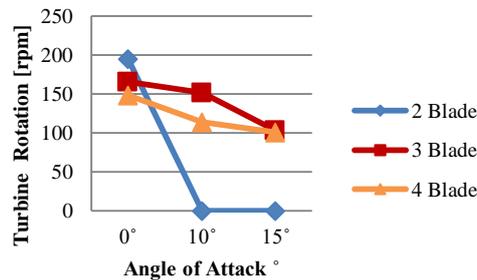


Figure 9. Graphic of comparison between angle of attack and turbine rotation.

Figure 9 showed that the best rotation was produced at 0° angle of attack with number of blades as much as 2 blades. At 10° and 15° angle of attacks, the turbine did not rotate because of stall phenomenon. Stall is an aerodynamic condition where lift coefficient is starting to decrease which caused by increasing angle of attack degree that goes beyond critical point limit. High angle of attack on a hydrofoil will cause separated fluid flow from hydrofoil surface which diminish lift force and increase thrust. If the angle of attack is decreased, the fluid flow will stay at hydrofoil surface [13].

The next step is conducting force measurement analysis produced by water velocity using equation 3 [13]. The measurement was conducted to compare analytic results with testing results. Water density at 30°C temperature is at 997 kg/m³. Fluid trajectory towards turbine rotor was at length x width = 0.22 m x 0.48 m. Fluid velocity obtained by using Pitot tube measurement tool was at 1.25 m/s.

$$P_{air} = \frac{1}{2} \times \rho \times A \times V^3 = \frac{1}{2} \times 997 \times 0,22 \times 0,48 \times 1,25^3 = 102.82 \text{ Watt} \quad (3)$$

To determine value of Performance Coefficient the turbine at 195.17 rpm rotation with turbine rotor spokes of 0.1 m, using equation 4 [12]:

$$TSR = \frac{\omega \cdot r}{v_{air}} = \frac{2\pi n r}{60 V_{air}} = \frac{2\pi \times 195,17 \times 0,1}{60 \times 1,25} = 1.63 \quad (4)$$

After getting TSR value and its inserted into Turbine Betz Limit Efficiency Graphic, it will get the value of Power Coefficient 0.01. Based on this value, turbine power can be measured by using equation 5 [13]:

$$P_{turbine} = C_p \times P_{taut} = 0,01 \times 102,82 = 1.02 \text{ Watt} \quad (5)$$

Based on that, determine Darrius Turbine efficiency using equation 6 [13].

$$\eta_{turbine} = \frac{P_{turbine}}{P_{air}} \times 100\% = \frac{1,02}{102,82} \times 100\% = 1\% \quad (6)$$

Based on those results, the highest power generated by DC generator was at 1.02 Watt, which produced by 2 blades Darrius Turbine at 0° angle with efficiency of 1%.

4. Conclusion

The highest rotation at 0° angle with 2 turbine blades have produced 195.17 rpm rotation and power 0.18 Watt. The highest efficiency 1% has been produced by Darrius Turbine with 2 blades at 0° angle. The optimum result has been produced by 4 blades turbine, because the turbine has been able to self-start at 0.77 m/s water velocity either at 0°, 10°, or 15° and has produced power 0.1 Watt.

Acknowledgments

Authors wish to acknowledge assistance or encouragement from our colleagues, our Department and our university, Universitas Trisakti that has already given us a chance to disseminate our research.

References

[1] Laws N D and Epps B P 2016 Hydrokinetic energy conversion: technology, research, and outlook

- Renew Sustain Energy Rev.* **57** 1245-1259
- [2] Prayoga W A and Permatasari R 2019 Perancangan dan Pemodelan Turbin Darrieus untuk Pembangkit Listrik Tenaga Arus Laut (PLTAL) *MESIN* **10** 1
- [3] Direktorat Jenderal Energi Baru dan Terbarukan 2014 *Potensi dan Peluang Investasi Energi Baru, Terbarukan, dan Konservasi Energi*
- [4] Purnama A C, Hantoro R and Nugroho G 2013 Rancang Bangun Turbin Air Sungai Poros Vertikal Tipe Savonius dengan menggunakan Pemandu Arah Aliran *J. Tek. ITS* **2** B278-B282
- [5] Vesenjak M and Hriberšek M 2014 *Flow Driven Analysis of a Darrieus Water Turbine* **60** 769-76
- [6] Nachtane M, Tarfaoui M, El Moumen A, Saifaoui D and Benyahia H 2019 Design and hydrodynamic performance of a horizontal axis hydrokinetic turbine *International Journal of Automotive and Mechanical Engineering* **16** 2 6453-6469
- [7] Khan M J, Bhuyan G, Iqbal M T and Quaicoe J E 2009 Hydrokinetic energy conversion systems and assessment of horizontal and vertical axis turbines for river and tidal applications : A technology status review *Appl Energy* **86** 1823-1835
- [8] Kaygusuz K and Gu M S 2010 *Hydrokinetic energy conversion systems : A technology status review* **14** 2996-3004
- [9] Mariasa K G and Suryawan A A A 2013 Karakteristik airfoil NACA “00XX” dengan variasi sudut serang *J. Ilm. Tek. Desain Mek.* **1** 61-68
- [10] Rehman W, Rehman F and Malik M Z A 2018 Review of Darius Water Turbines *Proc. ASME*
- [11] Muratoglu A and Yuce M I 2015 Performance Analysis of Hydrokinetic Turbine Blade Sections *Journal ISSN* **2**
- [12] Saini G and Saini R P 2018 Numerical Investigation of the Effect of Blade Profile of a Darrieus Hydrokinetic Turbine *2018 5th IEEE Uttar Pradesh Section International Conference on Electrical, Electronics and Computer Engineering (UPCON)* 1-6
- [13] Rajput E R K 2011 *Fluid Mechanics and Hydraulic Machines* (S. Chand & Company Ltd)
- [14] Brian Kirke and Leo Lazaukas 2008 Variable pitch darrieus water turbines *J. Fluid Sci. Technol.* **3**
- [15] Septyaningrum R H and Novel E 2018 Design of a vertical axis hydrokinetic turbine - straight blade cascaded (VAHT-SBC): experimental and numerical simulation *J. Eng. Technol. Sci.* **50** 73-86