# Variation Number of Blades for Performance Enhancement for Vertical Axis Current Turbine in Low Water Velocity in Indonesia

Madi, Shade Rahmawati, Mukhtasor, Dendy Satrio and Ahmad Yasim
*Department of Ocean Engineering, Institut Teknologi Sepuluh Nopember, Surabaya 60111, Indonesia*

Keywords: Vertical Axis Current Turbine, Number of Blades, Performance Enhancement, Low Water Velocity.

Abstract: Asosiasi Energi Laut Indonesia (ASELI) has provided the results of the ratification of the energy potential of ocean currents in Indonesia amounting to 17,989 MW. This amount is very large considering that Indonesia is classified as in low water velocity. The vertical axis current turbine is proposed by many researchers because they have lower performance than the horizontal axis current turbine. So this study proposes research to improve the performance of the vertical axis current turbine for low water velocity by varying the number of blades. The type of blade NACA $63_4021$ chose because has good performance for the vertical axis current turbine of Darrieus type. The model of the turbine is simulated by Computational Fluid Dynamics (CFD) with variations of the number of blades namely, 3, 4, and 5. The totals of the statistic element of meshing are 16,090, 167,020, and 174,375 at the number of blades 3, 4, and 5, respectively. The inlet velocity set at 1.5 m/s and tip speed ratio (TSR) are 1.5, 2, and 2.5. The final results of this study show that the blade numbers can improve the performance of the turbine model on all TSR ranges. The blades 4 and 5 are increased by 21.8% and 15% respectively from the blades 3 on TSR 2.5. The highest performance is obtained by the number of blades 4 on TSR 2.5 with the value of the power coefficient (Cp) 0.26.



## 1 INTRODUCTION

One of the technologies that are usually used for the current energy source is the turbine. The turbine is the main equipment in addition to the generator (Madi et al., 2019). Generally, the turbine that is used in the world operated in the higher current speed, such as in Columbia 1.5-2.5 m/s (Rawlings, 2008), Italy 2 m/s (Castelli et al., 2013), China 3-4 m/s (Jing, 2014), Korea 3 m/s (Quang Le et. al, 2014), and Australia 1.5-2 m/s (Marsh et al., 2015). Whereas several potential locations in Indonesia are classified in the low water velocity, they can only achieve a maximum current speed of 1.39, 1.5, and 1.79 m/s at Riau strait, Boleng strait and Mansuar strait, respectively (Mukhtasor et al., 2014; Satrio et al., 2018). So, the turbine which already exists in the world, cannot be applied in Indonesia.

Asosiasi Energi Laut Indonesia (ASELI) has provided the results of the ratification of the energy potential of ocean currents in Indonesia amounting to 17,989 Megawatt (Mukhtasor et al., 2014). The amount is very abundant considering that Indonesia is classified as in the low water velocity. Therefore, the turbine is needed that can be applied in the low water velocity in Indonesia.

In general, the turbine consists of two based on its rotating axis namely, the vertical axis current turbine (VACT) and horizontal axis current turbine (HACT) (Khan et al., 2009; Hydrovolts, 2006 and Duvoy et al., 2012). The VACT can respond to any flow direction, so the results of efficiency will stable. Whereas the HACT only responds in one flow direction, so the results of efficiency will not stable (Kirke and Lazauskus, 2011; Zeiner, 2015; Bachant and Wosnik, 2015; Satrio et al., 2016). Therefore, this study case will focus on the design of VACT.

Particularly, the VACT consists of two namely, Darrieus type and Savonius type (Khan et al., 2009). The turbine of the Darrieus type is higher efficiency than the Savonius type. However, in practice, the efficiency is still under the HACT. It is a challenge for researchers in this research. This study case will try to improve efficiency the VACT of Darrieus type in the low water velocity, by varying the number of blades 3, 4, and 5 (Fig. 1). The blades are simulated by Computational Fluid Dynamics (CFD).



Madi, ., Rahmawati, S., Mukhtasor, ., Satrio, D. and Yasim, A.
Variation Number of Blades for Performance Enhancement for Vertical Axis Current Turbine in Low Water Velocity in Indonesia.
DOI: 10.5220/0010047900470053
In *Proceedings of the 7th International Seminar on Ocean and Coastal Engineering, Environmental and Natural Disaster Management (ISOCEEN 2019)*, pages 47-53
ISBN: 978-989-758-516-6

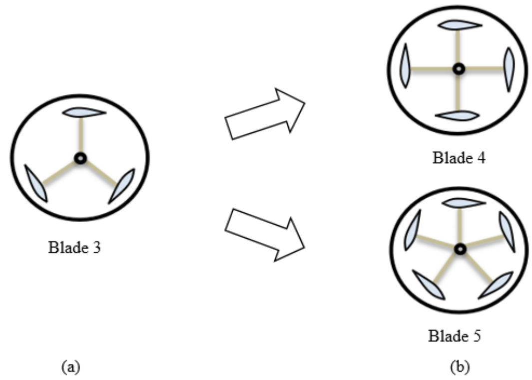


Figure 1: (a) Basic turbine, (b) variations turbine.

The type of blade NACA $63_4021$ is chosen for this study because it is similar to the morphology of humpback whales flippers (Fish and Battle, 1995). The humpback whales are the most maneuverable of other species and have a symmetric body so that they will be stable and fast to catch prey (Johari et al., 2007). The blade profile of NACA $63_4021$ in the VACT of Darrieus type has a good performance (Marsh et al., 2015). The profile of NACA $63_4021$ can be shown in Fig. 2.

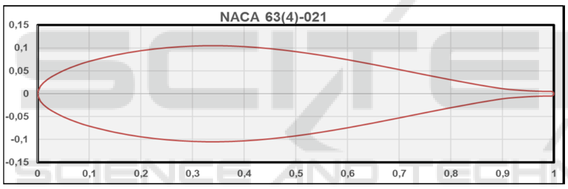


Figure 2: The profile of NACA $63_4021$.

# 2 NUMERICAL SIMULATIONS

## 2.1 Turbine Geometry

Three types of turbine designs are simulated to evaluate the influence of variations of the number of blades. The turbine geometry (Table 1) is used based on the published 3D CFD model data by Marsh et al (2015). The turbine with three blades namely basic turbine (Fig. 1a) is designed and simulated for compared with the results of the 3D CFD model by Marsh et al (2015). After that, the variations turbine (Fig. 1b) is designed and simulated to obtain the influence of the performance of the turbine.

Table 1: Turbine Geometry.

| Geometry | Dimensions |
|---|---|
| Blade type | NACA $63_4021$ |
| Chord length (C) | 0,065 m |
| Number of blades (N) | 3, 4 and 5 |
| Diameter of turbine (D) | 0,914 m |
| Height of turbine (H) | 0,686 m |

## 2.2 Key Performance Parameters

The performance parameters of the turbine blades are investigated for this study namely, solidity ($\sigma$), torque ($T$), and power of the turbine *($P_t$)*.

The solidity of the turbine is defined as the ratio of rotor blade surface area to the frontal, swept area that the rotor passes through (Li, 2010), where,

$$\sigma = \frac{NC}{2\pi R} \tag{1}$$

where $N$ is the number of blades, $C$ is chord length (m), and $R$ is the radius of the turbine (m).

The torque of the turbine represents the torque coefficient. The comparison of torque of the turbine and hydrodynamic subsystem is called by the torque coefficient *(Ct),* where,

$$Ct = \frac{T}{0{,}5\,\rho\,A\,V^2\,R} \tag{2}$$

where $p$ is the density of the water (998.2 kg/m$^3$), $A$ is the turbine swept area *(HxD),* and $V$ is current velocity (m/s).

The power of the turbine represents the power coefficient *(Cp),* where,

$$Cp = \frac{P_t}{P_a} \tag{3}$$

where $P_t$ is the power mechanic of the turbine (watt) and $P_a$ is the power kinetic of the water (watt).

The power of the turbine is obtained from the value of the torque and the rotational speed, shown in equation 4. Whereas the power kinetic is obtained of available in the water (equation 5).

$$P_t = T \; x \; \omega \tag{4}$$

where $\omega$ is the rotational speed (rad/s) and $T$ is the torque of the turbine (N.m).

$$P_a = 0{,}5 \; p \; A \; V^3 \tag{5}$$

## 2.3 Boundary Conditions

The dimension of domain boundary in this study is determined namely 10D x 20D (Fig. 3). The length and width of domain boundary 20D and 10D respectively were studied and recommended by Marsh et al (2015). The domain boundary consists of two main zones, namely, rotary, and stationary for using the meshing method. The position of the circular turbine is on the 5D from the inlet, 15D from the outlet, and in the middle of the symmetry wall.

The boundary conditions are simulated in the 2D CFD model with the use of free stream conditions. In this study case, the turbine without use arms and shaft. The inlet and outlet conditions are set in the velocity of 1.5 m/s and pressure 0 Pa, respectively. The walls are set as symmetry so that the fluid has the same distributions at the top and bottom of the walls.

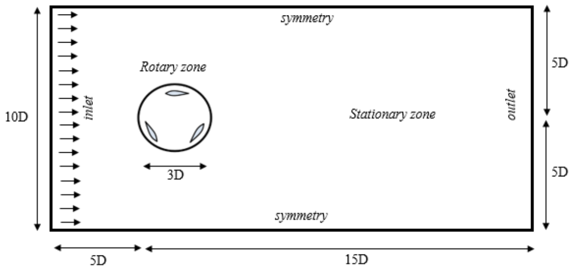


Figure 3: Domain boundary of the turbine model.

## 2.4 Meshing

The meshing is part of designing CFD simulations, a net strategy which is a process that determines the final results of design studies using CFD. The use, the number of elements in the meshing that is more and finer will produce a better the final results, and vice versa. However, the number of elements that are many and smooth requires a long time. So, it takes a meshing strategy with smooth elements and not at the same time. In this study, the statistics of meshing elements are used 16,090, 167,020, and 174,375 at the blades 3, 4, and 5, respectively. The number of elements based on the criteria for grid independence a study was conducted by Marsh et al (2017).

In this study, the structure of meshing uses the triangle method. The process of meshing structure in the 2D CFD model is arranged so that the rotary zone is made denser than the stationary zone and the blade zone is made denser than the rotary zone. The results of the meshing structure in this study can be shown in Fig. 4.

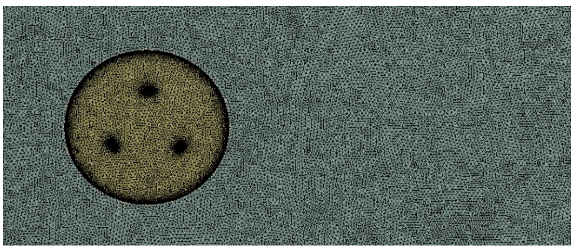

Figure 4: Meshing of domain boundary the basic turbine.

The mesh density is refined (Fig. 5) in the area of the blades, interior fluids, and interface zone by specifying the relevance center, smoothing, span angle center, face sizing, and edge sizing to receive hydrodynamic flow (Marsh et al., 2015). Edge sizing in all areas the turbine blades are the same at 0.0004 m. And then face sizing in the area of the turbine and the interior fluids are set at 0.05 m and 0.054, respectively.

The Inflation layers are utilized to control cell heights near all the turbine blades wall to resolve the boundary layer flow (Marsh et al., 2015), shown in Fig. 6. According to recent studies, the inflation layer set at 20 layers and the global growth rate set at 1.2 (Satrio et al., 2018).

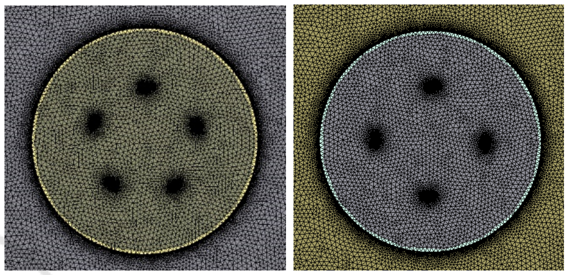

Figure 5: Refinement meshing of the variations turbine.

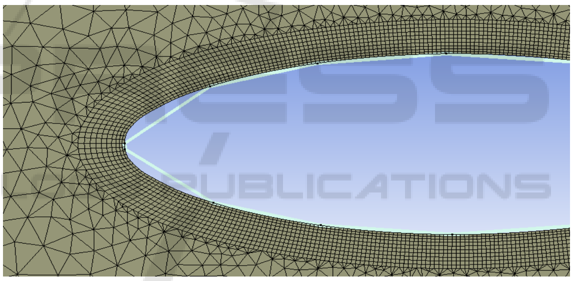

Figure 6: Inflation layers of the blade.

## 2.5 Solver Setup

In this study uses 6 core internal parallel processing for simulation the turbine blades with 2D CFD. The code is used to solved incompressible turbulence of Unsteady Reynolds Averaged Navier Stokes (U-RANS) equations. The *k-ω* SST turbulence model is utilized because it has a good accuracy model both free stream and boundary layer region (Marsh et al., 2016). Beside that often is used by researchers for vertical axis current turbines (Dai and Lam, 2009; Castelli et al., 2010; S Lain, 2010; Malipeddi and Chatterjee, 2012; Marsh et al, 2012, 2013 and 2014). The setting of the solution method at pressure velocity uses Semi-Implicit Method for Pressure Linked Equation (SIMPLE) for algorithm scheme and overall is set as second-order.

In this research simulation generally uses general transient type settings for an application to water fluid types. General transient type settings for an application to water fluid types. So that in the material setting choose the type of fluid that is water with a density of 998.2 kg/m$^3$. Furthermore, at the cell zone condition step, to input the rotational speed at TSR 1.5, 2, and 2.5 are 4.92 rad/s, 6.56 rad/s, and 8.21 rad/s, respectively. The current speed data is set at the boundary condition-stage of 1.5 m/s.

After that, residual monitor for convergence is set at overall equation $10^{-4}$ and the maximum of iteration is 70. The input of calculation simulation is the number of time step (NTS) and time step size (TSS). In this study uses increment angle 0,9 degree and 6 rotation of turbine at all TSR. TSS represents the addition of angles each time the turbine rotates and NTS represents how many turbines rotated during the simulation (Satrio et al., 2018).

# 3 RESULTS AND DISCUSSION

## 3.1 Verification of 2D CFD Model

Verification this study of 2D CFD model simulation is carried out against was published data of the 3D CFD model by Marsh et al (2015). This study case compares the basic turbine 2D CFD with the 3D CFD model, shown in Fig. 7. The curve of Cp-TSR shows that the result of simulation 2D CFD has a similar trend with simulation 3D CFD. The result of Cp in this study shows that at TSR 1.5 represents low water velocity, different 16% with the 3D CFD model data. Differences in the value of Cp due to the use of different model dimensions and this study without uses of arm and shaft model design. Generally, at the 2D CFD model turbine by researchers without use arm and shaft.

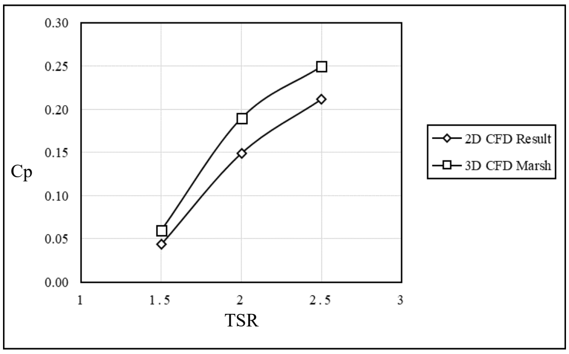


Figure 7: Verification 2D CFD result with the published 3D CFD data.

## 3.2 Effect of Blade Number on Torque

The first performance parameter in this study case is about the torque of the turbine. Output simulation with the 2D CFD model is data of torque coefficient (Ct) to represent the torque of the turbine. The curve of Ct-TSR in Fig. 8, shows the value of Ct and TSR at the basic turbine (blade 3) and the variations turbine (blades 4 and 5).

The value of Ct will determine the value of torque by using equation 2. The value of the torque at all the turbine blades is shown in Table 2.

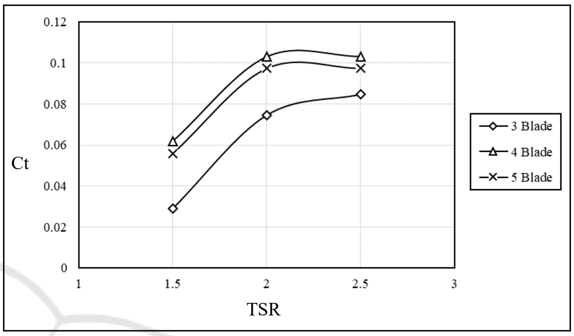


Figure 8: Ct-TSR curve at all the turbine blades.

Table 2: The value of torque (N.m).

| TSR | T 3 blade | T 4 blade | T 5 blade |
|---|---|---|---|
| 1.5 | 9.353 | 19.925 | 17.983 |
| 2 | 23.996 | 33.185 | 31.330 |
| 2.5 | 27.278 | 33.229 | 31.352 |

Based on Fig. 8 and Table 2 show that at all TSR, the blades 4 are higher torque than the blades 3 and 5. This study uses at TSR below 3 because it represents low water velocity. This study shows that at all low TSR ranges the blades 4 have the best performance with torque parameters. The torque of the blades 4 is increased by 21.8% from the blades 3, whereas the blades 5 is increased by 15% from the blades 3 or is decreased by 5.6% from the blades 4. So, this study shows that performance enhancement in the low water velocity is obtained by the turbine blades 4, with torque parameters.

## 3.3 Effect of Blade Number on Solidity

The second performance parameter in this study case is about the solidity of the turbine. The value of turbine solidity is obtained by using equation 1. The more the number of blades, the greater the value of turbine solidity (σ) is shown in Table 3.

Table 3: The value of solidity.

| The number of blades (N) | The value of solidity (σ) |
|---|---|
| 3 | 0.07 |
| 4 | 0.09 |
| 5 | 0.11 |

Based on Table 3 show that the turbine blades 3, 4, and 5 have the value of solidity 0.07, 0.09, and 0.11, respectively. The effect of solidity on the turbine performance can be shown through a curve Cp-TSR, in Fig. 9. The power coefficient increase with the increase in turbine solidity from the turbine blades 3 (σ = 0.07). However, at the turbine solidity, 0.11 represents the turbine blades 5 decreases from blades 4. The authors predict that this is due to a loose lift force because of the turbine more solid. The highest Cp occurs at TSR 2.5 on blades 4 with a value of 0.26. However, the solidity 0.09 represents the turbine blades 4 improve performance to 21.8%. So, this study shows that performance enhancement in the low water velocity is obtained by the turbine blades 4, with solidity parameters (σ = 0.09).

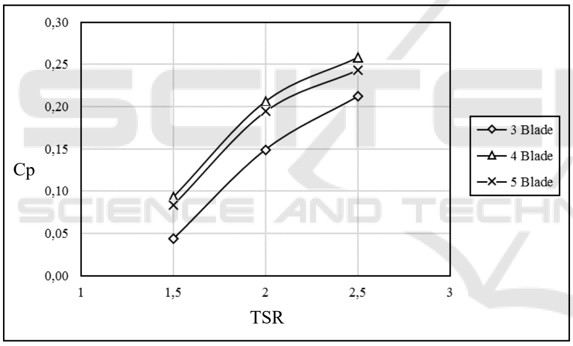


Figure 9: Cp-TSR curve at all the turbine blades.

### 3.4 Effect of Blade Number on Power

The third performance parameter in this study case is about the power of the turbine. The value of power is determined by the rotational speed (ω) in rad/s using equation 4. The curve of *P-ω* in Figure 9 shows the effect of blade number on power (P) with the input of rotational speed namely, 4.92 rad/s, 6.56 rad/s, and 8.21 rad/s.

Based on Fig. 10 shows that the power of the turbine is influenced by rotational speed according to equation 4. The correlation between power output and rotational speed are comparable. The higher the rotational speed is the higher the power in watt at all blade numbers. The highest power occurs at TSR 2.5 on blades 4 with a value of 273 watts. The power of the blades 4 is increased by 21.8% from the blades 3, whereas the blades 5 is increased by 15% from the blades 3 or is decreased by 5.6% from the blades 4. However, the value of power at the turbine blades 4 to improve performance to 21.8% from blades 3. So, this study case shows that performance enhancement in the low water velocity is obtained by the turbine blades 4, with power parameters.

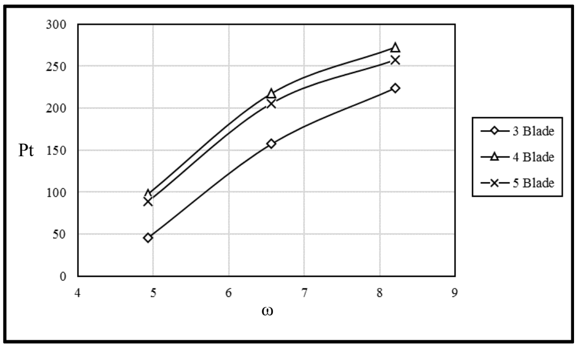


Figure 10: The results of the turbine power.

## 4 CONCLUSIONS

The simulation of variation of the number of blades 3, 4, and 5 successfully is done. The final results of this study case show that the number of blades can improve the performance of the turbine model on all low TSR ranges. The blades 4 and 5 are increased by 21.8% and 15% respectively from the blades 3 on the TSR 2.5. The highest performance is obtained by the number of blades 4 on TSR 2.5 with the value of Cp 0.26. So, this study case will choose the blades 4 for further research with the experimental method.

## ACKNOWLEDGEMENTS

This research is done with the assistance of several parties. Authors thanks to the team research and appreciation to the directorate general of resources for science, technology, and higher education; the ministry of research, technology, and education; the Republic of Indonesia, which fund this research on the scheme called, “The Thesis Magister Research” under decree number 6/E/KPT/2019 on 02/19/19, and contract number 5/E1/KP.PTNBH/2019 and 778/PKS/ITS/2019 on 03/29/19, and on the scheme called, “The Basic Research” under decree number 6/E/KPT/2019 on 02/19/19, and contract number 5/E1/KP.PTNBH/2019 and 847/PKS/ITS/2019 on 03/29/19.

# REFERENCES


Bachant, P. and Wosnik, M. (2015). *Performance measurements of cylindrical- and spherical- helical crossflow marine hydrokinetic turbines, with estimates of exergy efficiency.* Renew Energy.

Castelli, M.R., G. Ardizzon, L. Battisti, E. Benini, G. Pavesi. (2010). *Modeling strategy and numerical validation for a Darrieus vertical axis micro-wind turbine*. in: ASME 2010 International Mechanical Engineering Congress and Exposition, Vancouver, British Columbia, Canada.

Dai YM, W. Lam. (2009). *Numerical study of straight-bladed darrieus-type tidal turbine*. Proc. Institution Civ. Eng. Energy.

Duvoy, P., Hydrokal., T. H. (2012). *A Moduleforin-stream Hydro Kinetic Resource Assessment*. Computer & Geosciences. 39: 171–81.

Fish, F. E., and Battle, J. M. (1995). *Hydrodynamic Design of the Humpback Whale Flipper*. Journal of Morphology,pp.5160.doi:10.1002/jmor.1052250105. Vol. 225

H. Johari, C. Henoch, D. Custodio, and A. Levshin. (2007). *Effects of Leading-Edge Protuberances on Airfoil Performance*, AIAA Journal Vol. 45, No. 11.

Hydrovolts. (2006). *In-stream Hydrokinetic Turbines. Power tech Labs,* Available from hydrovolts.com.

Jing, Fengmei. (2014). *Experimental Research on Tidal Current Vertical Axis Turbine with Variable-Pitch Blades.* Ocean Engineering, 88:228-241.

Khan, M. J., Bhuyan, G., Iqbal, M. T., Quaicoe, J. E. (2009). *Hydro kinetic Energy Conversion Systems and Assessment of Horizontal and Vertical Axis Turbines for River and Tidal Applications*: A Technology Status Review. *Applied Energy.* 86(10): 1823–35.

Kirke, B. K. and Lazauskas, L. (2011). *Limitations of fixed pitch Darrieus hydrokinetic turbines and the challenge of variable pitch*. Renewable Energy 36 2011 893-897: Elsevier.

Li, Shengmao dan Yan Li. (2010). *Numerical study on the performance effect of solidity on the straight-bladed vertical axis wind turbine*. Scientific Research Fund of Heilongjiang Provincial Education Department (No.:1153h01); Scientific Research Foundation for the Returned Overseas Chinese Scholars.

Madi, M E N Sasono, Y S Hadiwidodo and S H Sujiatanti. (2019). *Application of Savonius Turbine behind The Propeller as Energy Source of Fishing Vessel in Indonesia*. IOP Conf. Series: Materials Science and Engineering, IOP Publisher.

Malipeddi A.R. and D. Chatterjee. (2012). *Influence of duct geometry on the performance of Darrieus hydroturbine*. Renew. Energy.

Marsh, D. Ranmuthugala, I. Penesis, G. Thomas. (2012). *Three dimensional numerical simulations of a straight-bladed vertical axis tidal turbine.* in: Proceedings of the 18th Australasian Fluid Mechanics Conference, Launceston, Tasmania.

Marsh, D. Ranmuthugala, I. Penesis, G. Thomas. (2013). *Performance predictions of a straight-bladed vertical axis turbine using double-multiple streamtube and computational fluid dynamics*. J. Ocean Technol.

Marsh, D. Ranmuthugala, I. Penesis, G. Thomas. (2014). *Numerical simulation of straight-bladed vertical axis turbines,* in: 2nd Asian Wave and Tidal Energy Conference (AWTEC), Tokyo Japan.

Marsh, D. Ranmuthulaga, I. Penesis and G. Thomas. (2015). *Three dimensional numerical simulation of straight-bladed vertical axis tidal turbines investigating power output, torque ripple and mounting force*, Renewable Energy 83 67-77: Elsevier.

Marsh, D. Ranmuthulaga, I. Penesis and G. Thomas. (2015). *Numerical investigation of the influence of blade helicity on the performance characteristic of vertical axis tidal turbine*, Renewable Energy 81 926-935: Elsevier.

Marsh, D. Ranmuthulaga, I. Penesis and G. Thomas. (2016). *Numerical simulation of the loading characteristics of straight and helical-bladed vertical axis tidal turbines*. Renewable Energy 94 418-428: Elsevier.

Marsh, D. Ranmuthulaga, I. Penesis and G. Thomas. (2017). *The influence of turbulence model and two and three-dimensional domain selection on the simulated performance characteristics of vertical axis tidal turbines*, Renewable Energy 105 106-116: Elsevier.

Mukhtasor, Susilohadi, Erwandi, Pandoe, W., Iswadi, A., Firdaus, A. M., Prabowo, H., Sudjono, E., Prasetyo, E. dan Iluhade, D. (2014). *Potensi Energi Laut Indonesia*. Badan Litbang Kementrian Energi dan Sumberdaya Mineral (ESDM) dan Asosiasi Energi Laut Indonesia (ASELI).

Quang Le, Kwang Soo Le, Jin Soon Park and Jin Hwan Ko. (2014). *Flow-driven rotor simulation of vertical axis tidal turbines: A comparison of helical and straight blades*. Int. J. Nav. Archit. Ocean Eng.

Rawlings G. (2008). *Parametric characterization of an experimental vertical axis hydro turbine*. MSC dissertation. University of British Columbia.

Satrio, Dendy., I.K.A.P Utama., Mukhtasor. (2016). *Vertical Axis Current Turbine Advantages and Challenges Review*. Proceeding of Ocean, Mechanical and Aeroscope. Science and Engineering Vol.3, Hal. 64-71. Universiti Malaysia Terengganu, Malaysia.

Satrio, Dendy., I.K.A.P Utama., Mukhtasor. (2018). *The influence of time step setting on the CFD simulation result of vertical axis tidal current turbine*. Journal of Mechanical Engineering and Sciences. Volume 12, Issue 1, Hal. 3399-3409. UMP Publisher.

Satrio, Dendy., I.K.A.P Utama., Mukhtasor. (2018). *Numerical Investigation of Contra Rotating Vertical-Axis Tidal Current Turbine*. Journal of Marine Science and Application. Hal. 3399-3409. UMP Publisher.

Satrio, Dendy., I.K.A.P Utama., Mukhtasor. (2018). *Performance Enhancement Effort for Vertical Axis Current Turbine in Low Water Velocity*. Proceeding of The 4th Asian Wave and Tidal Energy Converence (AWTEC). National Taiwan Ocean University, Taiwan.

S. Lain. (2010). *Simulation and evaluation of a straight-bladed darrieus-type cross flow marine turbine*. J. Sci. Industrial Res.

Winchester, J.D. dan Quayle S.D. (2009). *Torque ripple and variable blade force: A comparison of Darrieus and Gorlov-type turbines for tidal stream energy conversion*. Proceedings of the 8th European Wave and Tidal Energy Conference, Uppsala, Sweden.

Zeiner-Gundersen, D. H. (2015). *A novel flexible foil vertical axis turbine for river, ocean, and tidal applications.* Applied Energy 151 2015 60–66: Elsevier.