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Study of the Motion Performance of Marine Current Power Plant Turbine Floaters Due to Ocean Current Forces Under Moored Conditions

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Abstract

Indonesia targets carbon emissions to reach 0% in 2060 and is replaced by optimizing the use of renewable energy sources. Indonesia as an archipelago country, with the potential of thousands of straits can be utilized as a source of ocean currents as a source of electrical energy. The electricity generated is obtained from a turbine rotor that rotates due to the force of the ocean current flow. To support the turbine rotor to move in the sea, a floating support structure is needed. In this study, a trimaran tipe support structure is used where on the left and right sides are installed 2 (pieces) turbine rotors @ 50 kW each, so that the total has a capability of 200 kW (@4 x 50 kW). The novelty of this study is the utilization of Trimaran technology in marine current power generation turbines, which has good stability, low resistance, and a wider deck area rather than monohull structures. A numerical study using Computational Fluid Dynamics (CFD) is used to calculate the program. The results showed that the floater only moves backward and then is pulled forward with a small amplitude of movement in the X-direction, while those on the Y and Z axes are insignificant. The turbine floater can be immediately stabilized and the turbine rotor will rotate due to the force of the ocean current received. Therefore, in this study, the marine current turbine using trimaran type is showing good ability to survive in Indonesian waters even in high current areas.

1. Introduction

Environmental health threats due to excessive utilization of fossil energy sources result in health problems, droughts, crop failures, unclear weather changes, world disasters, and others. The need to immediately switch to Renewable Energy sources (RE) is an urgent need for the future of our children and grandchildren. At this time, we can feel the threat in our daily lives. The extreme rise in temperature can result in the melting of polar ice caps, increasing the volume of sea water and resulting in the occurrence of el nino, landslides, storms, and so on. The increase in population, and agricultural and industrial activities contribute to the destruction of the ozone layer in the earth's atmosphere [1]. In connection with these threats, the Government is trying hard to reduce these impacts through an accelerated program to increase the contribution of renewable energy sources. In 2025, it is planned that the contribution of renewable energy will be 23% and by 2060 it is expected to achieve 0% utilization of fossil energy sources, and completely all the energy consumed will be from the results of renewable energy sources (NZE 0%). But the target seems difficult to achieve, considering that this year, the contribution of renewable energy has only reached 11.2% [2].

Utilization of renewable energy sources will be very important in the future. Researchers from all over the country are competing to contribute the results of research that has been carried out. The country that first succeeds in providing solutions to its research findings will be the winner in the future. We can no longer be just spectators and users of technology resulting from research on renewable energy sources. Countries that master the technology of utilizing renewable energy will become winners in the world's economic and political life. We as a country that has abundant renewable energy sources, must try hard so that the sources in our country are not controlled by other countries. For Indonesia as a country with thousands of large and small islands, the utilization of renewable energy resources from the sea is quite large but has not been widely explored. The RE sources consist of several energy resources as listed in Table 1 [3].

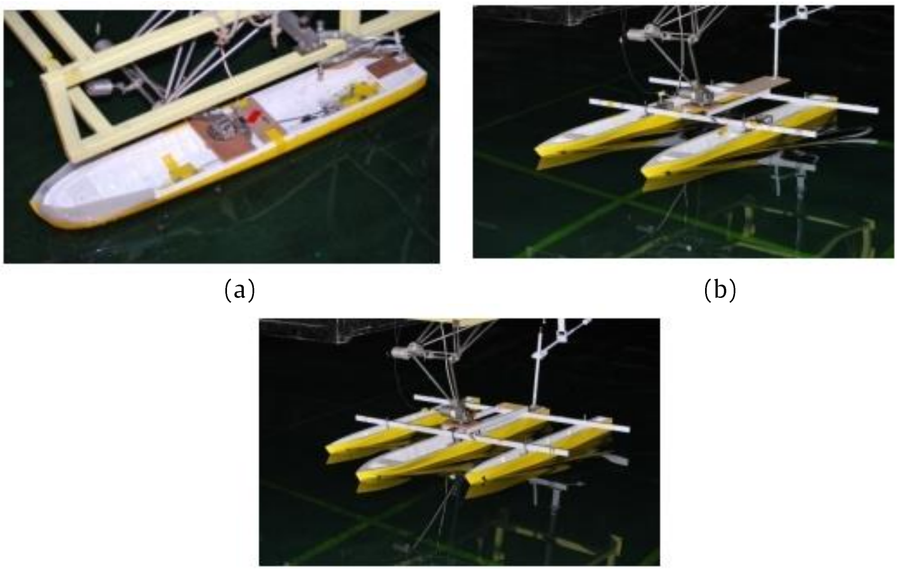
Unfortunately, in Table 1, it is mentioned that RE sources from the sea, which have a potential of 60 GW, are still not utilized at all (0 GW) compared to other RE sources that have been widely utilized. Meanwhile, in many countries, there has been a rapid development of tidal current energy system to convert the energy in seawater into electrical energy [4]. This opportunity must be immediately utilized through optimization of research results on the potential of EBT sources from the sea. Utilization of the potential for energy sources from the sea is so important. Even though Indonesia is very rich in natural resource potential, Indonesia is very vulnerable to price change shocks and easily enters the global economic crisis compared to other developing countries [5]. Therefore, the Government must encourage the utilization of the potential of the sea including the potential energy sources from the sea for the welfare of the nation.

Since 2006 Indonesian Hydrodynamic Laboratory (IHL) BPPT has conducted research and developed a technology converts the ocean energy resources into electricity, the kinetic energy of marine current and the potential energy of wave [6]. The turbine is supported by a fixed of floating system to prop and keep the turbines in a specific site. According to several study, the floating system is more suitable to extract tidal current energy potentials near the seawater surface [7]. In its development, the turbine rotor operation can be supported by a mast placed on the seabed (fixed) or supported by a catamaran or trimaran-shaped float where the turbine rotor is installed in the centre between the hulls.

Table 1. The potential of renewable energy in Indonesia

No	Energy resource	Potential (GW)	Utilization (GW)
1	Solar	3.295	0.27
2	Hydro	95	6.69
3	Bio energy	57	3.09
4	Wind	155	0.15
5	Geothermal	24	2.34
6	Sea	60	0
	Total	3.686	12.54

The monohull ship type have been widely used in many years. But nowadays, the use of multihull ship is significantly increase due to its better transverse ability. The ship used in this study is a trimaran. Trimaran is a ship consisting of three hulls, namely one mainhull which is in the middle and has larger dimensions, and two demihulls which are on the sides of the ship and have smaller dimensions [8]. The design of trimaran hull is aimed to form a less resistance at high velocity [9]. The utilization of trimaran type ships has been used for researchers in ship design because of the small resistance element. Besides having advantages in transverse direction stability and having a wider deck than the monohull type of ship. This type also has a smaller total resistance value so that it can be applied to almost all types of ships that require small resistance values, such as fast boats, cruise ships, fishing boats, warships, and others. Murdijanto et al. [10] have carried out testing of resistance differences between monohull, catamaran, and trimaran ships (Figure 1). The results of the analysis show that catamaran and trimaran ships produce smaller resistance values than the monohull type. This shows that the addition of empty space at the bottom of the ship is able to accelerate the flow of water and reduce the resistance value. From the advantages mentioned above, trimaran technology is more widely used in ship operations, both for warships, ships, fish, passenger ships, tourist ships, research ships, and others.


(a) (b)

(c)

Figure 1. (a) Monohull vessel, (b) catamaran vessel, and (c) trimaran vessel [10].

Under practical operation conditions, hydrodynamic characteristics of floating horizontal-axis turbine are affected by the wave-induced motion response of the floating platform for the turbine system [11]. Ship resistance is defined as the force required to tow the ship in calm water at a constant velocity. Wave making resistance occurs due to energy lost because it is used in the formation of waves as an interaction between the hull that moves water along with the movement of the ship. In mooring an ocean current turbine, the mooring system is an important component, because it is to keep the turbine in stable condition (not moving position) [12]. Kai et al. [13] explains that the performance of the mooring system will affect the cost of floating offshore wind turbines in shallow water and the durability in extreme conditions so that the turbines can be dragged by the current. It is claimed that the concept has maximum strength against the risk of rope breakage, reduces the length of mooring ropes, and can withstand extreme conditions in shallow water areas. Junianto et al. [14] conducted a design study of a catamaran-type ocean current turbine that was refined into a quadspar floater turbine on mooring where the results showed that in the previous design, the monohull turbine showed a turbine rotation was insignificant in influencing the motion response of the floating structure of the current power system. The motion response system of the floating support structure could reduce the performance of the turbine. Also, the rotation of the turbine can increase the talli stress of the mooring system used.

In this study, a trimaran turbine is generated in marine current power. As previously explained, a trimaran is used due to its good stability, low resistance and a wider deck area to place electrical, mechanical equipment and operator operational. To understand more about the characteristic and optimization of trimaran as a current power turbine, numerical study using Computational Fluid Dynamics (CFD) were conducted to calculate the program.

2. Method

BRIN has conducted studies on the development of ocean current turbines with catamaran-type floaters since 2009 through model testing and 2 kW and 10 kW scale prototype testing. In this study, ANSYS commercial software was employed for the numerical simulation to investigate the platform behavior whilst operating in ocean currents at a certain velocity. The ocean current flow was set as fully incompressible flow and for the turbulence model, the k-ω SST was used. The simulation was solved at unsteady conditions, with the time step $\Delta t = 0.001$ second, and internal iteration 20. The overset mesh technique was applied in the computation domain to simulate the motion of the platform. During the simulation, the 6 DOF was activated to represent the motion of the platform. The ocean current velocity at 1 - 5 m/s was fed to inlet boundary conditions whilst the air velocity above the sea surface was set to 0 m/s.

In the numerical simulation, to simulate the flow that passes the marine current power plant turbine floaters, the computational domain is split into two parts, the motion and stationary subdomains. The motion subdomain covers the floaters while the stationary subdomains cover the rest. The overset mesh technique was applied in the whole computation domain so that it needs the interface between those two subdomains. The mesh of the motion subdomain can slide into the stationary subdomain. This technique requires that the mesh nodes at two interfaces are equivalent at each time step.

The width of the computational domain is set to $5B$ where B is the breadth of the whole floaters. The outlet of the computational domain is set at a distance of $10B$ from the inlet one. Figure 2 shows the schematic view of the computational domain. Since the simulation involves saltwater and air, the Eulerian multiphase fluid material is applied to the computational domain. The saltwater with a density of 1023 kg/m^3 is chosen as the heavy liquid fluid, whilst the air density above the water surface is set as light fluid. The flow in the computational domain is assumed incompressible flow and fulfills Reynolds Averaged Navier-Stokes (RANS) equations. The k-ω SST turbulence model is applied to the flow. The volume of fluid method (VOF) is employed to model the interaction between water and air at the surface of water. The uniform marine current speed is fed to the inlet of the computational domain. The velocity is set to 1-5 m/s with interval 1 m/s.

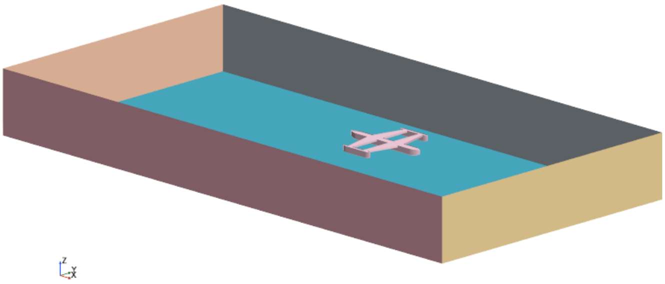


Figure 2. Schematic view of the computational domain

Figure 3 are the process design of 200 kW- marine current turbine which is implemented by BRIN. It shows the numerical design and manufacturing process at laboratory workshop. The turbine are designed as a trimaran. The holes between the left and right hulls are for the placement of turbine rotors, 2 (two) each on the left side @ 50 kW and 2 (two) on the right side @ 50 kW. Floater size data as follows is explained in Table 2.

Table 2. The dimension of the marine current turbine

Parameter	Unit	Size
Length (main hull)	m	25
Length (side hull)	m	10
Breadth (main hull)	m	21.88
Breadth (side hull)	m	1
Height	m	1.7
Draught	m	0.55
Displacement	m^3	69.47

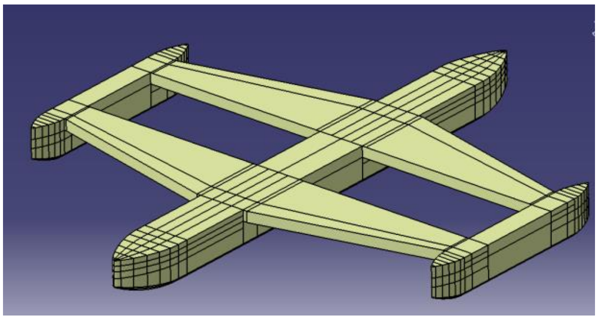
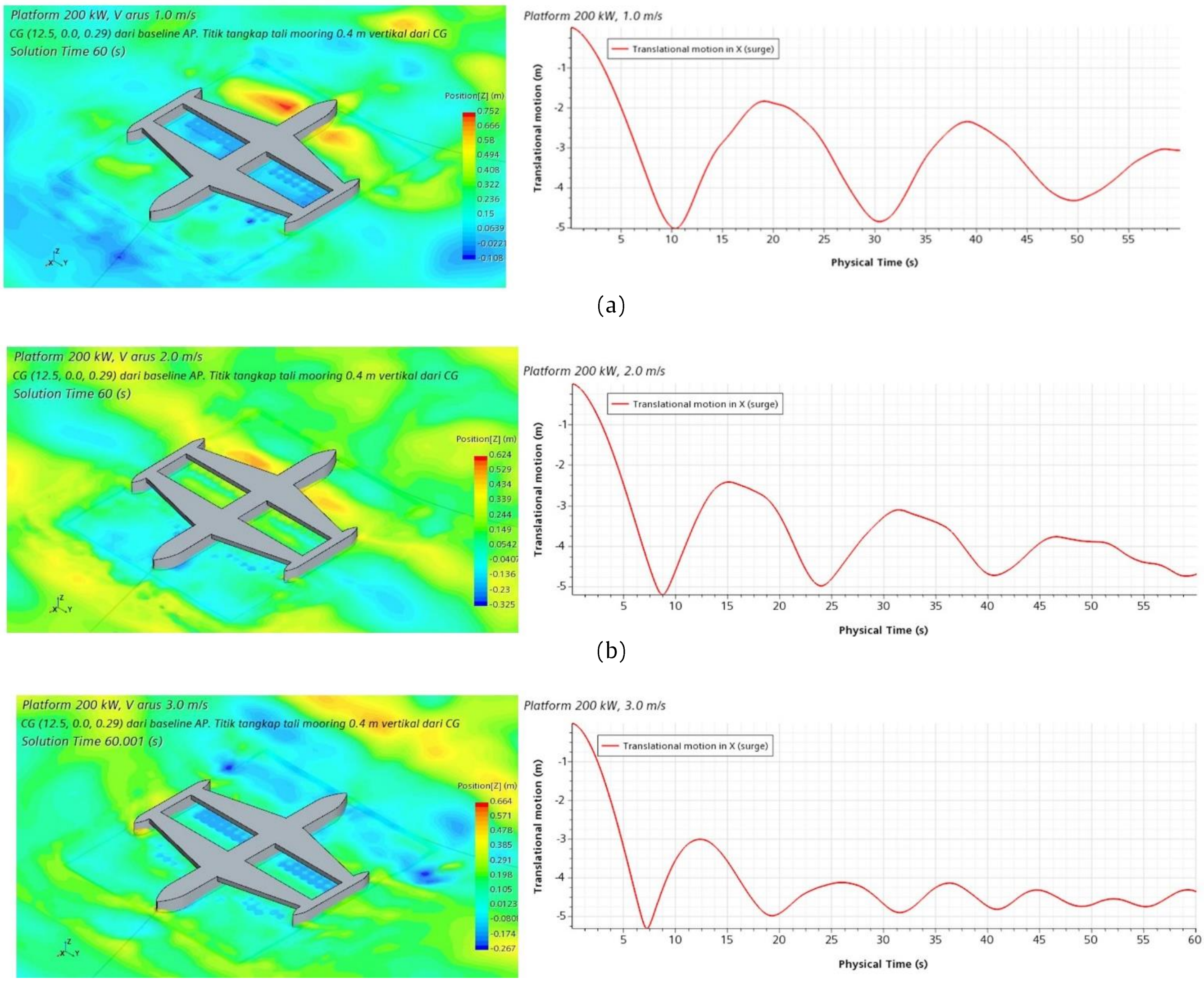


Figure 3. Isometric design of the 200 kW marine current turbine

3. Result and discussion

In this study, a trimaran support structure is used where on the left and right sides are installed 2 (pieces) turbine rotors @ 50 kW each, so that the total has a capability of 200 kW (@4 x 50 kW). The novelty of this study is the utilization of Trimaran technology in marine current power generation turbines, which has good stability and a wider deck area than monohull structures for the purposes of placing electrical, mechanical and operator operational equipment.

The numerical process of the installation of an ocean current turbine when moored were generated. The direction of the ocean current is assumed to only come from the front of the turbine (x-axis), seeing that the movement in the direction of the Y and Z axes are not significant. Numerical calculations of the resistance of the 200 kW Marine current turbine platform were carried out using Computer Fluid Dynamic (CFD) software. The turbine platform is conditioned to be moored at sea so that it is at rest. However, the floater platform still has a movement force in the X, Y and Z axis directions due to the force of ocean current pressure. The graph of the movement and force that occurs when the platform receives the force of ocean current velocity in meters per second (m/s) of 1 to 5 m/s.



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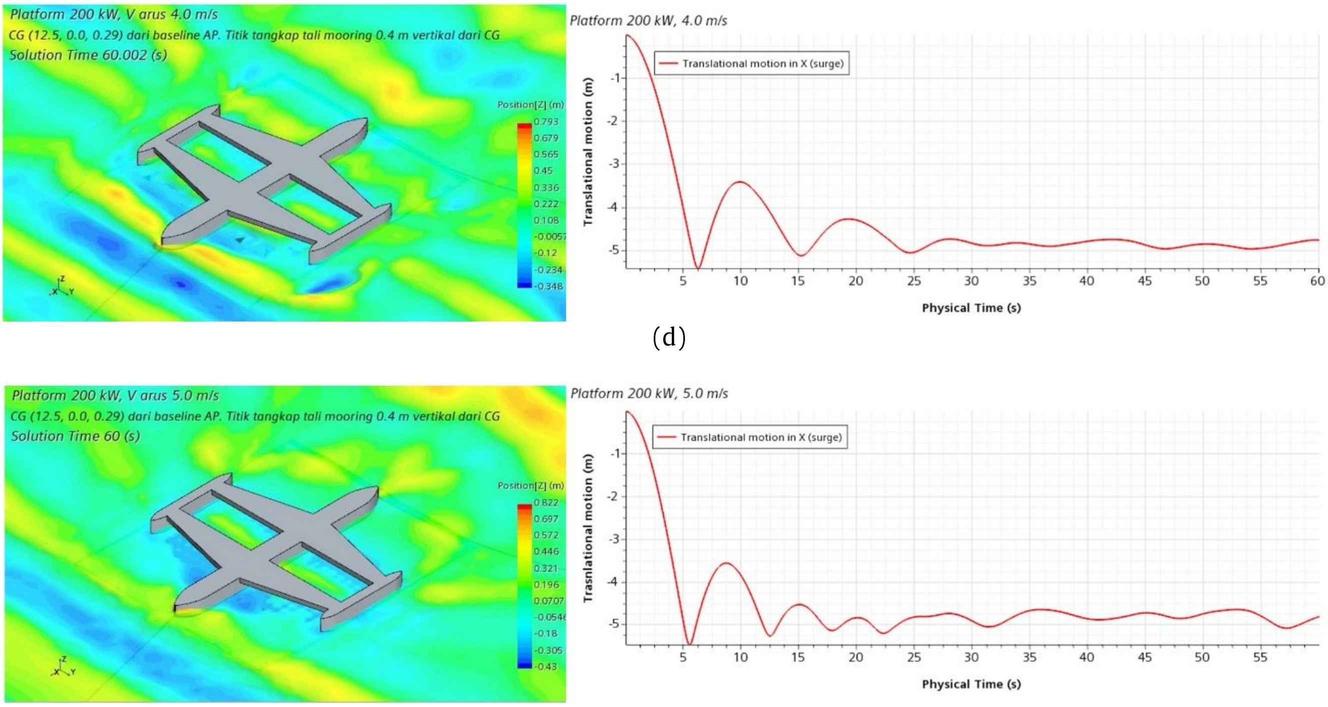


(d)

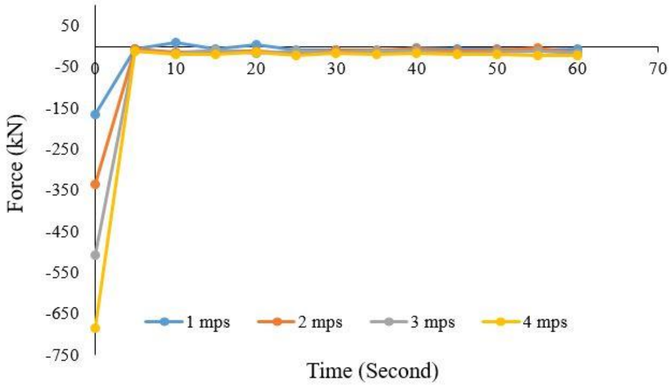
(e)

Figure 4. The contour of seawater surface (heaving motion) at time 60 s and the translational motion in various velocity - x axis where (a). 1 m/s, (b). 2 m/s, (c). 3 m/s, (d). 4 m/s, and (e). 5 m/s

Figure 4 shows the contour of seawater surface and translational motion in the direction of the X (velocity 1 m/s to 5 m/s), while Figure 5 shows a graph of the forces received on the hull of the floater platform due to the force of the ocean currents received. Figure 4 shows the effect of the force of the ocean current received from the front direction (condition of the moored platform) so that the platform experiences translational motion (meters) in the longitudinal (X axis), lateral (Y axis) and vertical (Y axis) directions as a function of time (seconds).

From the results of the calculation, the average velocity of surface ocean currents in Indonesian in 2002-2009 is in the range of 0.450-0.550 m/s [15]. While the results of the calculation in 2013-2015, the value of the highest surface ocean currents occurs in the east season (June-July-August) with a value of 0.054-0.193 m/s [16]. Another study is explained that mostly the maximum speed of the marine current of many straits in Indonesia are in order 1 - 2 m/s [7]. Therefore, in this study, the value of ocean currents of 1-5 m/s already show the ability of this current marine turbine to survive in Indonesian waters, even in high current season. The current velocity was set at 1 m/s to 5 m/s.

In the current velocity of 1 m/s, the fluctuation of heaving is greater than at a larger current velocity. As can be seen in Figure 4(a), the contour of seawater surface shows that there is a high heaving motion area in the left body of the trimaran, as indicated by the red-orange area in the contour. This is in line with the graph of the translation motion in Figure 4(a), where at solution time of 60 s and velocity of 1 m/s, the time needed to stabilize the turbine reached more than 1 minute. At higher current velocity, the time required is lower, reaching 25 seconds at a current velocity of 4 m/s and 17 seconds at current velocity of 5 m/s. The contour of seawater surface at Figure 4(d) and 4(e) for current velocity of 4 m/s and 5 m/s respectively show that the fluctuation of turbine heaving motion is not as great as in current velocity of 1 m/s. The red-orange area that indicates a high fluctuation of turbine motion does not exist. From the results of the simulations carried out, it is shown that higher current velocity is managed to stabling the turbine faster and back to the original position. The turbine floater can be immediately stabilized and the turbine rotor will rotates due to the force of the ocean current received.



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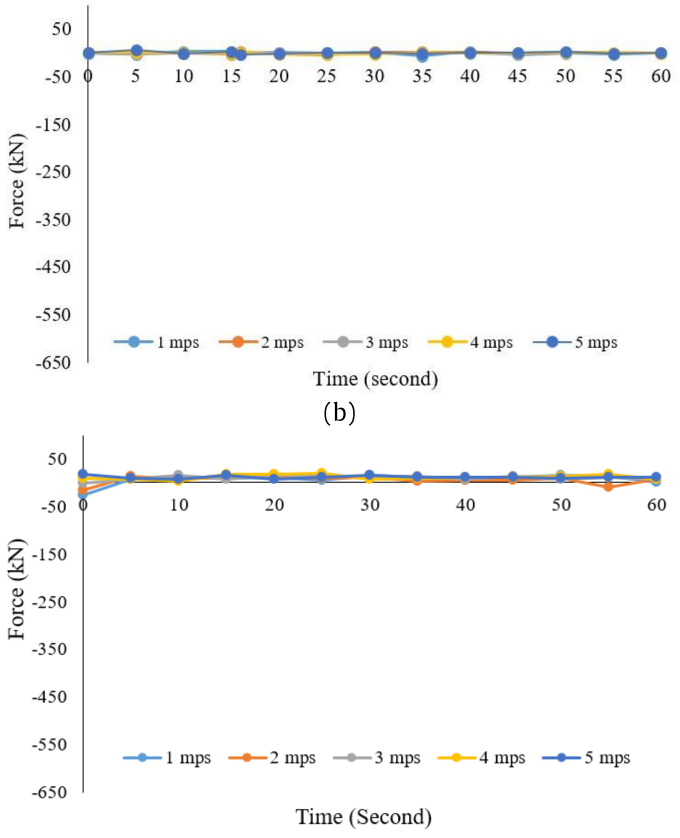

(c)

Figure 5. The current force in direction of a). X-axis direction, b). Y-axis direction, and c). Z-axis direction

Figure 5 generally show the ocean current forces received on the platform (X,Y and Z axis directions) at velocity of 1 m/s, 2 m/s, 3 m/s, 4 m/s and 5 m/s. The results showed that the floater only moves backward and then is pulled forward again with a small amplitude of movement in X-direction, while those on the Y and Z axes are not significant that they can be ignored. In general, it can be seen that the greater the velocity of the current received, the greater the thrust force will occur, resulting in the platform being pushed back (which is marked with a negative sign.) After that, due to the force of the mooring rope, causing the platform to be pulled forward again. Figure 5(a), in the X-axis direction, from second 0 to second 5, the platform experiences the initial pressure force of the ocean current from the front of the platform which causes it to be pushed back 5 meters within 5 seconds. Subsequently, the platform moved forward again due to the influence of the mooring attraction by 1.5 meters. This condition is repeated until the platform is stable (due to the influence of the pull-press force of the mooring rope). In Figure 5(b), relatively experiencing the same phenomenon, namely at the time of the initial pull, the platform experienced a position retreat of 7 meters to the rear and Figure 5(c) shows the platform retreated by 5 meters. While in the direction of the Y and Z axes, the force of the ocean current is not very influential because the force of the ocean current received is the force in the X-axis translation direction so that for the Y and Z axis directions it does not have a significant effect.

4. Conclusion

The simulation using CFD have been successfully applied to determine the performance of resistance due to ocean current forces in the condition of the floater platform moored at sea. At the beginning of the current pressure, the platform is pushed backward. Because the platform is moored, the platform is held until the mooring rope is taut, for the next mooring rope pull force, the floater platform will be "pulled" forward. In this condition, the turbine rotor begins to rotate with the velocity of the ocean current. The resulting electrical energy is stored in an electric generator and transmitted to shore.

From the results of the simulations carried out, it is shown that higher current velocity is managed to stabling the turbine faster and back to the original position. The turbine floater can be immediately stabilized and the turbine rotor will rotates due to the force of the ocean current received. The floater only moves backward and then is pulled forward again with a small amplitude of movement in X-direction, while those on the Y and Z axes are not significant that they can be ignored. In general, it can be seen that the greater the velocity of the current received, the greater the thrust force will occur, resulting in the platform being pushed back (which is marked with a negative sign.) After that, due to the force of the mooring rope, causing the platform to be pulled forward again. Therefore, in this study, the marine current turbine using trimaran type is showing good ability to survive in Indonesian waters even in high current areas.

The numerical study in this paper needs to be validated in physical testing in order to obtain a more real picture of the performance behaviour of the ocean current turbine floater. It is expected that the trimaran type will be a new breakthrough in the utilization of ocean current energy sources in Indonesia, especially for floating type turbines in moored conditions. Since the total breadth of the floaters (21.88 m) is almost the same as its total length (25 m), it needs further investigation concerning the mooring technique of the floaters. Furthermore, the simulation should be integrated with the behaviour of the vertical axis marine current turbine converter so that the loads work at floaters represent the real condition.

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Reference

[1] J. Kartikaweni, "Global Warming : Sebuah Ancaman bagi Kehidupan Makhluk Hidup di Bumi." [Online]. Available: iesr.or.id

[2] A. Pribadi, "Menteri ESDM : Perlu Upaya Konkrit dan Terencana Capai Target Bauran 23% Di Tahun 2025." [Online]. Available: ebtke.esdm.go.id

[3] A. Pribadi, "Potensi Energi baru terbarukan di Indonesia." [Online]. Available: www.esdm.go.id

[4] H. Jeffrey and A. B. E. Melo, "Ocean energy systems annual report: An overview of ocean energy activities in 2018," 2018.

[5] Y. Rochwulaningsih, S. T. Sulistiyono, N. N. Masruroh, and N. N. Maulany, "Marine policy basis of Indonesia as a maritime state: The importance of integrated economy," *Marine Policy*, vol. 108, pp. 103602, 2019.

[6] S. Junianto, Mukhtasor, R. W. Prastianto, and C. H. Jo, "Effects of demi-hull separation ratios on motion responses of tidal current turbines-loaded catamaran," *Ocean System Engineering*, vol. 10, no. 1, pp. 87–110, 2020.

[7] Erwandi, D. Rahuna, and C. S. J. Mintarso, "The development of the IHL wave-current turbine to convert the ocean energy from both wave and current," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 588, no. 1, 2019

[8] W. Adinata, B. A. Adietya, and A. F. Zakki, "Analisa Kekuatan Struktur Trimaran Dengan Glass Bottom di Perairan Karimunjawa Menggunakan Metode Elemen Hingga," *Kapal: Jurnal Ilmu Pengetahuan dan Teknologi Kelautan*, vol. 14, no. 1, pp. 21–25, 2017

[9] J. Tupan and R. B. Luhulima, "A Comparison of Monohull, Catamaran, Trimaran Vessels Based on Operational Review of Fuel Use," *International Journal of Engineering Research & Technology*, vol. 9, no. 12, pp. 431–436, 2020

[10] Murdijanto, I. K. A. P. Utama, and A. Jamaluddin, "An Investigation Into the Resistance/Powering and Seakeeping Characteristic of River Catamaran and Trimaran," *MAKARA Technology Series*, vol. 15, no. 1, 2011.

[11] L. Zhang, S. Wang, Q. Sheng, F. Jing, and Y. Ma, "The effects of surge motion of the floating platform on hydrodynamics performance of horizontal-axis tidal current turbine," *Renewable Energy*, vol. 74, pp. 796–802, 2015.

[12] S.-M. Lin, C.-T. Liauh, and D.-W. Utama, "Design and Dynamic Stability Analysis of a Submersible Ocean Current Generator Platform Mooring System under Typhoon Irregular Wave," *Journal Marine Science and Engineering*, vol. 10, no. 4, p. 538, 2022.

[13] K. Wang, Y. Chu, S. Huang, and Y. Liu, "Preliminary design and dynamic analysis of constant tension mooring system on a 15 MW semi-submersible wind turbine for extreme conditions in shallow water," *Ocean Engineering*, vol. 283, p. 115089, 2023.

[14] S. Junianto, Mukhtasor, R. W. Prastianto, and W. Wardhana, "Motion Responses Analysis for Tidal Current Energy Platform: Quad-Spar and Catamaran Types," *China Ocean Engineering*, vol. 34, no. 5, pp. 677–687, 2020.

[15] R. Widyastuti, E. Y. Handoko, and Suntoyo, "Pemodelan Pola Arus Laut Permukaan di Perairan Indonesia Menggunakan Data Satelit Altimetri Jason-1," *Geoid*, vol. 6, no. 1, pp. 011–016, 2010.

[16] Y. Oktavia, J. Pratama, and Apriansyah, "Estimasi Arus Laut Permukaan Yang Dibangkitkan Oleh Angin Di Perairan Indonesia," *Prisma Fisika*, vol. VI, no. 1, pp. 1–8, 2018.