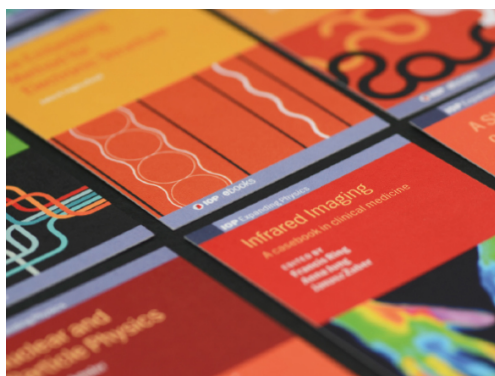


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The Effect Of Wind Turbine On Sea Flow

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Abstract. Indonesia is a maritime country that had quite extensive territorial waters, one of which was located in the East Kalimantan region. Despite having a large enough water area, only 30 percent of new marine products were used. Marine resources, especially fisheries in Indonesia, were very abundant but had not been utilized to the full, so it needs to be made offshore cages with the concept of aquaculture. Pembangkit Listrik Tenaga Bayu (PLTB) was renewable alternative energy for the coastal region. To support the development of this technological innovation, this study discussed the movement of ocean currents under the influence of wind turbines. The governing equation consists of the Shallow Water Equation and the wind turbine model. After the governing equation is formed, the model is solved numerically and the effect of wind turbines on sea flow can be observed. The influence of wind turbines on sea currents is large enough that it needs to be reviewed in the planning of developing wind turbines in the offshore sea area.

1. Introduction

East Kalimantan had a water area of 10217 square km. Even though it had a fairly large water area, only 30 percent or 102.3 thousand tons of newly utilized marine products were managed from the total production of 341 thousand tons. The Ministry of Maritime Affairs and Fisheries has a technology modernization program in the field of marine culture, namely offshore marine aquaculture or Keramba Jaring Apung (KJA) that had been built including in Sabang, Karimun Jawa, and Pangandaran [1].

In the last five years (2011 - 2015) national aquaculture production showed a positive trend with an average increase of 19.08%. Marine resources, especially fisheries in Indonesia, were very abundant but had not been utilized to the fullest so that it needs to be built an offshore floating cage with the aquaculture concept. Aquaculture is the cultivation of aquatic organisms in brackish or marine environments [2]. Besides the aquaculture concept itself, the thing that supports the implementation of this concept is the availability of energy in offshore areas.

Pembangkit Listrik Tenaga Bayu (PLTB) is renewable alternative energy for the coastal area. The total potential can reach 60.6 Giga Watt (GW), PLTB is one of the great potentials in the development of national electricity, especially in areas that have potential wind speeds above 4 meters per second (m / s). Wind sources will be even greater at offshore locations with water depths greater than 50 m. Countries with narrow shallow waters (below 50 m), building floating wind turbines. The Makassar Strait off the coast of Kalimantan is categorized as a hyphen reaching a depth of 2500 meters.

Furthermore, combining locations for the concept of aquaculture with the concept of providing energy using offshore floating turbines is an integrated solution for fishermen, especially fishermen in East Kalimantan. This location determination needs to be done appropriately to enable synergy between the two. Both systems require a sufficient hyphen area above 100 meters, have other types of



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activities that are not many (such as ship channel and fishing area) and have logistics and infrastructure that can benefit both systems [3].

But on the other hand, technological innovations for floating turbine foundations that could withstand additional mechanical loads due to aquaculture equipment are needed. To support the development of these technological innovations, this study discusses the movement of seawater with the influence of wind turbines.

2. Methodology

In this section, we explain the mathematical model of the effect of wind turbine on sea flow. The model was formed from the combination of the Shallow Water Equation model and the wind turbine model. The Shallow Water Equation is formed from the law of mass conservation and the law of conservation of momentum, while the wind turbine is formed from the energy kinetic equation. After the governing equation is formed, the equation is solved by a numerical method.

2.1. Shallow Water Equation (SWE)

Shallow Water Equation or SWE is a hyperbolic system in conservation law that explains geophysical flows such as rivers, coastal areas, oceans, atmosphere, etc [4]. The SWE model is derived from the integration of mass conservation laws which are derived into continuity equations and momentum conservation laws which are derived into momentum conservation equations. This movement is influenced by wind pressure and water ripples. The movement of sea water currents using the SWE equation is stated as follows:

$$\eta_t + (Hu^c)_x + (Hv^c)_y = 0 \quad (1)$$

$$u_t^c + u^c u_x^c + u^c v_y^c = -\frac{\tau_x^b}{\rho_w} + \frac{\tau_x^w}{\rho_w} + \frac{A_h}{H} \{ (Hu_x^c)_x + (Hu_y^c)_y \} \quad (2)$$

$$v_t^c + v^c u_x^c + v^c v_y^c = -\frac{\tau_y^b}{\rho_w} + \frac{\tau_y^w}{\rho_w} + \frac{A_h}{H} \{ (Hv_x^c)_x + (Hv_y^c)_y \} \quad (3)$$

$u^c(x, y, t)$ and $v^c(x, y, t)$ are vectors that express the velocity of ocean currents in the x -axis and y -axis. $H(x, y, t) = \eta(x, y, t) + D(x, y)$ is the total depth of sea water, $\eta(x, y, t)$ is the elevation of sea water and $D(x, y)$ is average depth of sea water. τ_x^b and τ_y^b are bottom friction, τ_x^w and τ_y^w are wind friction, and A_h is the viscosity of sea water. The equation (1) states that the conservation of mass in the fluid is incompressible. The equation (2) and (3) express conservation of momentum of the x -axis and y -axis direction.

2.2. Kinetic Energy

Wind energy is energy that is always available in nature and is a source of clean and renewable energy. The process of utilizing wind energy through the flow of the wind will move the rotor (propeller) which causes the rotor to rotate in harmony with the blowing wind. Therefore, wind energy is kinetic energy caused by wind speed to be used to rotate the windmill angle. The kinetic energy equation as follows is formed from the equation [5].

$$F = m a$$

F is the force, m is the mass, and a indicates acceleration. The kinetic energy equation is formed from the multiplication of forces and time so that it becomes $E = F s$ and can then be written as $E = m a s$. Solid motion kinematics $v^2 = u^2 + 2as$ where u is the initial velocity of the object, can also be written $a = \frac{v^2 - u^2}{2s}$, it is assumed that the initial velocity of the object is zero, so $a = \frac{v^2}{2s}$ and the kinetic energy equation is obtained

$$E = \frac{1}{2} m v^2 \quad (4)$$

2.3. Staggered Grid Method

The staggered grid method is used for discretizing equations in incompressible and compressible flow simulations. discretization Using the staggered grid method can be done at smaller intervals to complete a partial derivative. Reducing the interval at discretization must be followed by reducing the time step to maintain the stability of the solution. This resulted in the time needed to run a computing program is getting longer, as well as the allocation of memory needed is greater. However, this method is capable of producing more realistic solutions than collocated grid discretization.

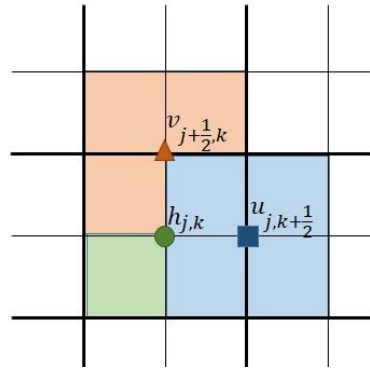


Figure 1. Staggered Grid Scheme

In this research, discretization is carried out using the volume method up to the staggered grid. The scheme is used is center time center space or known as the Leapfrog method. This scheme requires the calculation of values at a point involving values at the point before and after it. By applying the second-order leapfrog scheme around (x_k, y_j, t_n) for mass, around $(x_{k+\frac{1}{2}}, y_j, t_{n+\frac{1}{2}})$ for momentum x , and around $(x_k, y_{j+\frac{1}{2}}, t_{n+\frac{1}{2}})$ for momentum y , discretization of the mass component and momentum is given by

$$\begin{aligned} \eta_{j,k}^{n+1} &= \eta_{j,k}^n - \Delta t Adv_\eta \\ u_{j,k+\frac{1}{2}}^{n+1} &= u_{j,k+\frac{1}{2}}^n - \Delta t \left(g \frac{\eta_{j,k+\frac{1}{2}}^{n+\frac{1}{2}} - \eta_{j,k}^{n+\frac{1}{2}}}{\Delta x} + Adv_u \right) \\ v_{j+\frac{1}{2},k}^{n+1} &= v_{j+\frac{1}{2},k}^n - \Delta t \left(g \frac{\eta_{j+\frac{1}{2},k}^{n+\frac{1}{2}} - \eta_{j,k}^{n+\frac{1}{2}}}{\Delta y} + Adv_v \right) \end{aligned}$$

whereas for the oil thickness equation is given by $H_{j,k}^{n+1} = H_{j,k}^n - \Delta t Adv_H$. The Adv term is a non-linear term in the equation of mass and momentum. In this case the non-linear advection term is solved

using the Total Variation Diminishing (TVD) scheme [6] where the variable value is calculated using the upwind method.

3. Result and Discussion

In this section, we explain the equation of the movement of sea currents due to the influence of the wind turbine formed from the SWE and wind turbine models. In addition, the equation of the effect of wind turbine on sea flow will be solved by numerical methods.

3.1. Wind Turbine Equation

The kinetic energy equation that has been formed as in equation (4) is then reduced to time so that it becomes power or written P

$$E = \frac{1}{2}mv^2$$

$$P = \frac{dE}{dt} = \frac{1}{2} \frac{dm}{dt} v_w^2$$

v_w is the wind speed, $\frac{dm}{dt}$ is changed to $\frac{dm}{dt} = \rho A v_w$ where A is the area of the wind through so the above equation becomes $P = \frac{1}{2} \rho A v_w^3$. The actual mechanical power P_w extracted by the rotor blades in watts is the difference between the upstream and the downstream wind power, then

$$P_w = \frac{1}{2} \rho A v_w (v_u^2 - v_d^2) \quad (5)$$

where v_u is the upstream wind velocity at the entrance of the rotor blades in m/s and v_d is the downstream wind velocity at the exit of the rotor blades in m/s . We shall see later that these two velocities give rise to the blade tip speed ratio, we may write

$$\rho A v_w = \frac{\rho A (v_u + v_d)}{2} \quad (6)$$

v_w is the average of the velocities at the entry and exit of rotor blades of turbine. Equation (5) becomes $P_w = \frac{1}{2} \rho A (v_u^2 - v_d^2) \frac{(v_u + v_d)}{2}$ which may be simplified as follows:

$$\begin{aligned} P_w &= \frac{1}{2} \left[\rho A \left\{ \frac{v_u}{2} (v_u^2 - v_d^2) + \frac{v_d}{2} (v_u^2 - v_d^2) \right\} \right] \\ &= \frac{1}{2} \left[\rho A \left\{ \frac{v_u^3}{2} - \frac{v_u v_d^2}{2} + \frac{v_d v_u^2}{2} - \frac{v_d^3}{2} \right\} \right] \\ &= \frac{1}{2} \left[\rho A \left\{ \frac{1 - \left(\frac{v_d}{v_u}\right)^2 + \left(\frac{v_d}{v_u}\right) - \left(\frac{v_d}{v_u}\right)^3}{2} \right\} \right] \end{aligned}$$

or

$$P_w = \frac{1}{2} \rho A v_u^3 C_p \quad (7)$$

where $C_p = \frac{1 - (\frac{v_d}{v_u})^2 + (\frac{v_d}{v_u}) - (\frac{v_d}{v_u})^3}{2}$ or $C_p = \frac{(1 + \frac{v_d}{v_u})(1 - (\frac{v_d}{v_u})^2)}{2}$. The expression for C_p is the fraction of upstream wind power captured by the rotor blades. Let λ represent the ratio of wind speed v_d downstream to wind speed v_u upstream of the turbine, i.e.

$$\lambda = \frac{v_d}{v_u} \quad (8)$$

or

$$\lambda = \frac{\text{blade tip speed}}{\text{wind speed}}$$

3.2. Model the effect of wind turbine on sea flow

The effect of wind turbine on sea flow is a combination of SWE and wind turbine model. Wind turbine model as in equation (8) is added to the SWE momentum equation as in equation (2) and (3), so it can be written as

$$u_t^c + u^c u_x^c + u^c v_y^c = -\frac{\tau_x^b}{\rho_w} + \frac{\tau_x^w}{\rho_w} + \frac{A_h}{H} \{ (Hu_x^c)_x + (Hu_y^c)_y \} + P_{wx} \quad (9)$$

$$v_t^c + v^c u_x^c + v^c v_y^c = -\frac{\tau_y^b}{\rho_w} + \frac{\tau_y^w}{\rho_w} + \frac{A_h}{H} \{ (Hv_x^c)_x + (Hv_y^c)_y \} + P_{wy} \quad (10)$$

where $P_{wx} = \frac{1}{2} \rho A V_{ux}^3 C_p$ in x -axis and $P_{wy} = \frac{1}{2} \rho A V_{uy}^3 C_p$ in y -axis direction.

3.3. Numeric Solution

Equation (10) and (11) are further solved numerically for some values of the wind turbine by using numerical method. Numerical results will show the effect of wind turbine on sea flow velocity. The parameters used are $g = 9,81 \frac{m}{s^2}$, $\rho = 1.028 \frac{kg}{m^3}$, and $C_p = 0,59$. Figure (2) shows that the flow that hit the island forms turbulence and the flow of sea flow is relatively calm can be seen from the length of the arrow line that shows the resultant velocity vector. whereas in Figure (3) shows that the flow that hit the island is faster in forming turbulence and the speed of the sea current is relatively greater and irregular due to the effect of wind turbine.

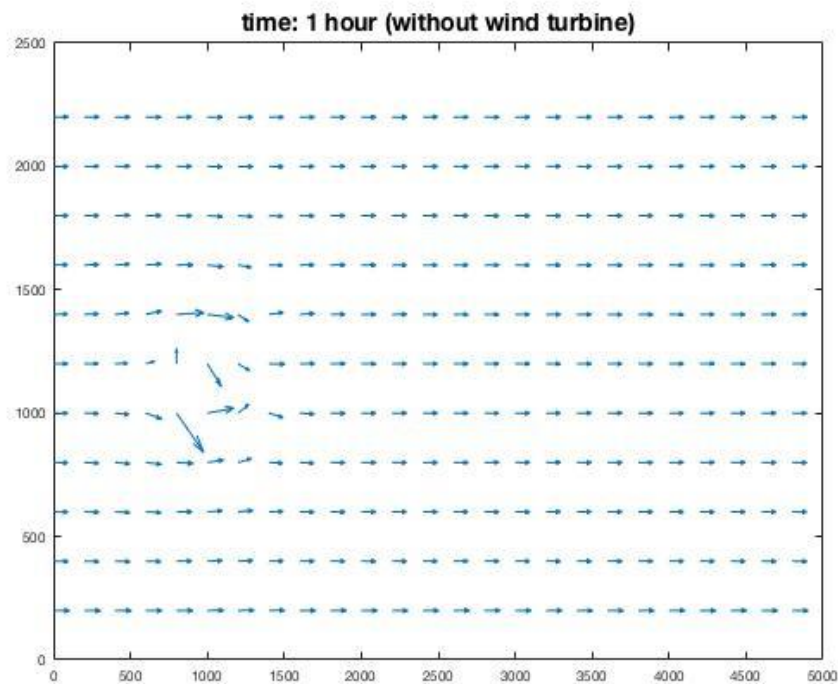


Figure 2. Sea flow without wind turbine at 1 hour

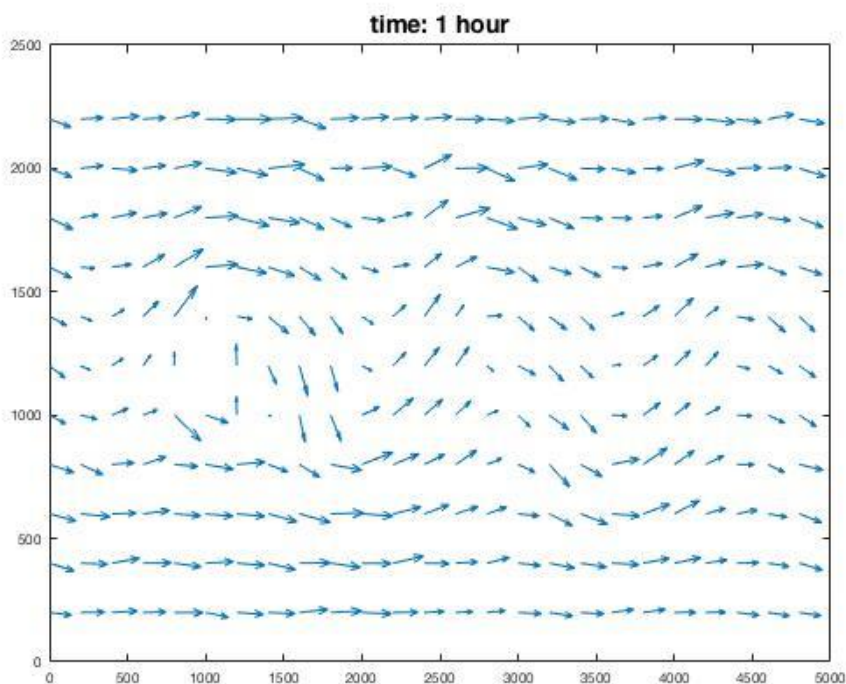


Figure 3. The effect of wind turbine on sea flow at 1 hour

After 12 hours, the sea flow that is not affected by the wind turbine, the longer the turbulence disappears and the flow of the sea flow is relatively calm which is shown in figure (4). While the sea

flow that is influenced by the wind turbine, turbulence is still quite clear and there is no change in the flow of the sea current that is relatively strong shown in figure (5).

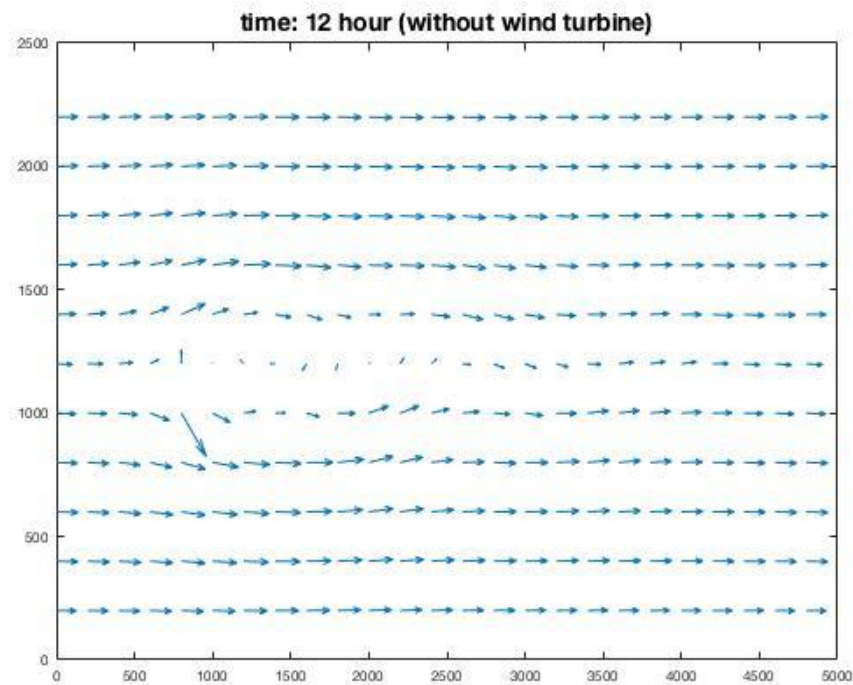


Figure 4. Sea flow without wind turbine at 12 hour

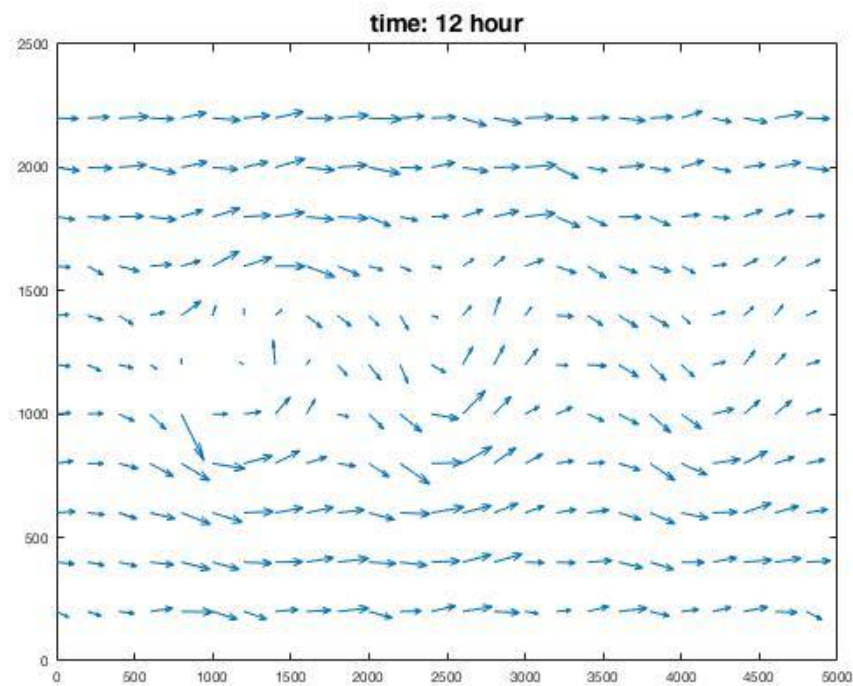


Figure 5. The effect of wind turbine on sea flow at 12 hour

Numerical simulation results show in addition to the wind, sea current flow is also determined by wind turbines. The presence of wind turbines causes turbulence more rapidly formed and the greater flow of the sea.

4. Conclusion

Based on this research it can be seen that the influence of wind turbine is quite large on changes in sea current flow velocity which can be seen in the length of the arrow line which shows the resultant velocity vector, so if the sea area will be given the wind turbine should be conducted in the planning of coastal structures (such as jetties, groins, seawall, breakwater, reclamation, etc.), the determination of the layout of the ports, shipping lanes, and management of the marine environment.

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