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Optimization of Ocean Wave Energy Harvesting with Pontoon Model–Single Pendulum

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ABSTRACT

Renewable energy is energy that is needed in this modern era. The need for electrical energy in the present is a primary need, much of the sustainability of human life is supported by the existence of electrical energy. We are in Indonesia where Indonesia is a country consisting of many islands, and 77% of Indonesia's territory is water. By utilizing the energy contained in ocean waves to make electrical energy by using sea wave power plants. Ocean wave energy harvsting, single pendulum pontoon systems, are one of the alternatives to energy problems in this world. Simulations were carried out to determine the electrical energy to be obtained from the from ocean wave energy harvesting, single pendulum pontoon system. The simulation was carried out with matlab software by controlling the variable amplitude of ocean waves 0.0125m, 0.025m, 0.0375m, 0.05 m, and 0.0625m. From the simulation results, current, power and voltage data generated from the ocean wave power generation system were obtained. In this study, the results obtained were different amplitude levels that had a real influence on the results of current, power and voltage generated from ocean wave energy harvesting - single pendulum pontoon system using minitab software to process data with a complete random design method. Where the higher the amplitude of ocean waves, the higher the value of the results of currents, voltages and power generated by single pendulum pontoon model from ocean wave energy harvesting.

Keywords: *Characteristics of electrical energy, Complete random design, Ocean wave energy harvesting,*

Introduction

Indonesia has many potential renewable energy resources that can be utilized to meet its electricity needs, including wave energy resources. There are several reasons why Indonesia needs sea wave power plants, namely utilizing renewable energy resources where renewable energy resources are environmentally friendly and can be produced sustainably. In addition, diversification of energy resources where Indonesia is currently heavily dependent on fossil fuel power plants such as coal, petroleum, and natural gas. Increasing the use of renewable energy resources such as ocean wave power can help reduce dependence on fossil energy resources. Ocean wave power plants have great potential because Indonesia has a very long coastline and many small islands scattered throughout its territory. Although wave power generation technology is still relatively new, there are already several companies that have successfully built and operated wave power plants in several countries, including in Scotland and Portugal. The Indonesian government has set a target to increase the proportion of renewable energy in the national energy mix to 23% by 2025. Utilizing ocean wave power can help achieve the targets set by the Government of the Republic of Indonesia. Ocean wave power plants with the single pendulum pontoon method are one of the technologies that can be utilized to produce electrical energy from ocean waves. Indonesia has a very large water area, so the potential to develop this technology is very large. Several studies have been conducted to develop this technology, one of which is research conducted by [1]–[3]. The study was conducted by varying the mass and arm of the pendulum on the pontoon, and using a water wave simulator to test the electrical energy generated. The results of this study show that the electrical energy produced can vary depending on the variation in mass and arm of the pendulum used. In addition, there is also research that discusses the characteristics of pendulum rotation in sea wave power plant simulators with pendulum systems.

Sea waves have several characteristics, including amplitude, wavelength, period, wave speed, carrying capacity, and free altitude. The amplitude or height of a wave is the vertical distance between the crests and

troughs of a wave. The wave height can vary from a few centimeters to several tens of meters depending on weather conditions and the depth of the sea. Wavelength is the horizontal distance between two peaks or two wave valleys. The wavelength also depends on weather conditions and ocean depth. The wave period is the time it takes for one wave to pass through a point. The wave period depends on the wavelength and speed of the wave. The speed of a wave depends on the depth of the ocean, wavelength, and acceleration of gravity. The deeper the ocean, the faster the waves move[4], [5]. The direction of coming is the direction from which the wave comes. The direction of incidence is influenced by the direction and strength of the wind. Transportability is the ability of a wave to carry water and material underneath. Freight power is very important for the formation of coasts and watersheds around the sea. Freeboard is the vertical distance between sea level and the deck of a ship. The free altitude must be considered in the planning of structures to be placed in the ocean such as ocean wave power plants. In contrast to [6] indicates attenuation in waves that have an area close to nuclear power plants. [7]–[9]using turbines to process ocean wave characteristics where additional sensors are given to simulate ocean wave characteristics to determine maximum results. [10] provides many variables in obtaining current, voltage and power data but to get the data requires a different type of plant, namely solar panels. [11] It uses sensors to monitor current and voltage. [12] Modify the equipment used by using a hybrid system where there are two forces in producing current and voltage, namely solar panel power and sea waves. [13], [14] varying the blades of wind speed to obtain results from the characteristics of ocean waves.

Complete randomized design is a statistical method used to test the effect of several factors on a response variable. In the context of ocean wave power plants, complete randomized design can be used to test the effects of factors such as wave height, frequency, and rotational speed on ocean wave power plants. Here are some materials that can help you understand complete random design for ocean wave power plants: One of the studies conducted used a complete randomized design to design a marine wave power plant with a circular rack and pinion system [15]This study used the Solidworks application to design parts of a sea wave power plant and conducted an animation simulation to determine the rotation generated. Another study discusses the planning of wave energy conversion instruments using oscillation column techniques [16], [17]This study designed three concepts of wave electric energy conversion tools by applying oscillating column techniques, choosing one concept from the three concepts designed, and analyzing the strength of electric current produced by wave power electric energy conversion tools by applying oscillating column techniques.

Other studies discuss solar cell power plants [18]This study discusses changes in waves and spectrum in solar power generation systems by using active filters using PI control using controlled rectifier loads with ignition angles of 35° -180°. [19]–[22]discusses the economic analysis of pneumatic conversion systems of ocean wave energy for power generation. This study discusses the economic analysis of sea wave-powered power plants with pneumatic systems to find out how economically this system is built, how much revenue is obtained from generator electricity results when compared to operational and maintenance costs [23]–[25] From some of the above studies, it can be concluded that complete random design can be used to design and analyze ocean wave power plants with a variety of different techniques and methods.

Research Methods

The research method applied to this study is carried out in several stages in obtaining data. The first is to model the mathematics of a gearbox consisting of several pairs of spur gears. After obtaining the mathematical model equations from the gear box, the mathematical equations are fed into the Simulink matlab to obtain the values of the current, voltage and power generated by the single pendulum pontoon model ocean wave power plant. The amplitude is varied to determine the effect of amplitude in producing current, voltage and power values, where amplitude variations start from 0.0125 m, 0.025m, 0.0375m, 0.05 m, and 0.0625m. The values of current, voltage and power were analyzed using a complete random design with the help of Minitab software to find out whether the amplitude generated from the high wave of sea water had a real effect in producing current, voltage and power in pontoon model marine power plants with a single pendulum. The pontoon model marine wave power plant is simulated by determining the gear box used as the transmission system. From the amplitude of seawater waves received by the sea wave power plant, it is transmitted using the gearbox arrangement below with the velocity ratio is 1 : 13

Gear 1 is Spur gear that gets input from pendulum with R_1= 21 mm
Gear 2 is Spur gear that gets input from gear 1 with R_2= 7 mm
Gear 3 and 3’ are Spur gears that get input from gear 2 with R_3= 15 mm
Gear 4 is Spur gear that gets input from gear 3 with R_4= 28.5 mm
Gear 5 is Spur gear that gets input from gear 4 with R_5= 20.5 mm

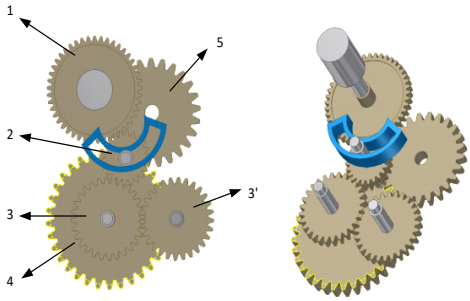

Figure 1. Gearbox

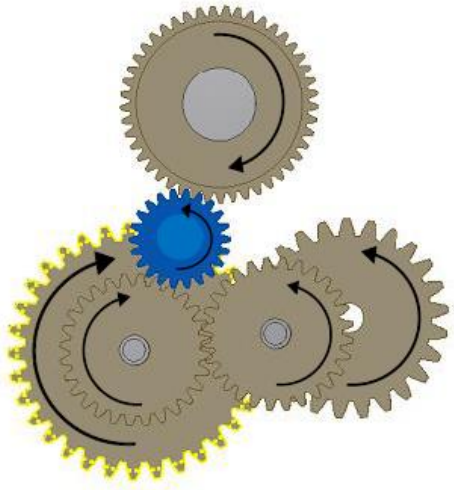

Figure 2. Direction of movement of gear rotation

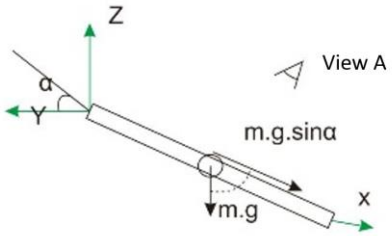

Figure 3. Analysis of pendulum movement

The movement of the pendulum as shown in figure 3 becomes the equation as in the formula (1) and analyze each gear in gear 1 as in Figure 4 below.

$$(ML^2)\ddot{\theta}_p + Mg \sin\alpha \sin\theta p\, L - C_T\dot{\theta}_p - K_{T1}(\theta_P - \theta_1) = 0 \quad (1)$$

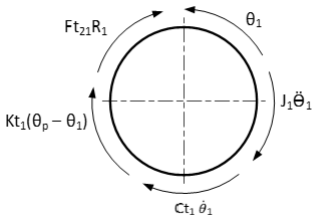

Figure 4. Angular velocity analysis in gear 1

After analyzing each gear, we get a mathematical equation. The equation (2) below is explaining gear ratio from gear input to gear output.

$$\left[\frac{R_3^2}{R_1^2}\frac{R_5^2}{R_4^2}J_1 + \frac{R_3^2}{R_2^2}\frac{R_5^2}{R_4^2}J_2 + \frac{R_3}{R_2}\frac{R_5^2}{R_4^2}J_3 + \frac{R_5^2}{R_4^2}J_4 - J_5\right]\ddot{\theta}_5 + \left[\frac{R_3^2}{R_1^2}\frac{R_5^2}{R_4^2}C_{T1} + \frac{R_3^2}{R_2^2}\frac{R_5^2}{R_4^2}C_{T2} + \frac{R_3}{R_2}\frac{R_5^2}{R_4^2}C_{T3} + \frac{R_5^2}{R_4^2}C_{T4} - C_{T5}\right]\dot{\theta}_5 + \left[\frac{R_3^2}{R_1^2}\frac{R_5^2}{R_4^2}K_{T1} + \frac{R_3^2}{R_2^2}\frac{R_5^2}{R_4^2}K_{T2} + \frac{R_3}{R_2}\frac{R_5^2}{R_4^2}K_{T3} + \frac{R_5^2}{R_4^2}K_{T4} + K_{T5}\right]\theta_5 + \frac{R_2}{R_1}\frac{R_5}{R_4}K_{T1}\theta_P + \frac{R_{11}}{R_6}K_{T3}\theta_{11} \quad (2)$$

The equation for the generator is obtained as equation 3. After entering the equation into Simulink Matlab, a simulink matlab model is formed as shown in figure 5.

$$Te = C_{T12}\dot{\theta}_{12} + J_9\ddot{\theta}_{12} + K_{T4}(\theta_{11} - \theta_{12}) \quad (3)$$

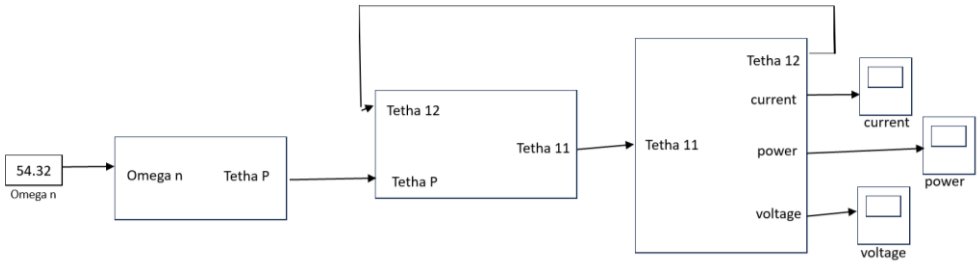

Figure 5. Modeling equations in Matlab simulink.

After running modeling with Simulink, natural values of current, voltage and power generated by the single pendulum pontoon model sea wave power plant were obtained as in table 1. After getting the results in table 1, another analysis was carried out using minitab software to find out whether the amplitude of sea waves had a real effect on the results of currents, voltages and power generated. The method used in minitab software is the complete random design method.

Results and Discussion

Discussion is the most important part of the overall content of scientific articles. The objectives of the discussion are: Answering research problems, interpreting findings, integrating findings from research into existing knowledge collections and compiling new theories or modifying existing theories. After conducting simulations on Simulink – Matlab, the data shown in table 1 and the equation for the amplitude shows in equation 4.

$$\alpha = \tan^{-1}\frac{\rho g H^2}{16 M g} \quad (4)$$

Table 1. Characteristics of ocean wave power plants

Amplitude (m)	Current (mA)	Voltage (mV)	Power (mW)
0.0125	1.158	5.79	6.704
0.025	1.203	6.016	7.237
0.0375	1.259	6.293	7.923
0.05	1.305	6.525	8.515
0.0625	1.316	6.581	8.661

From the modeling results in the matlab software, the characteristics of the voltage and power current values obtained from running the Simulink Matlab software as in table 1. The values in table 1 are used to determine whether the amplitude of ocean waves significantly affects the characteristics of ocean wave power

plants. The effect of amplitude on current results with the initial hypothesis that setting different amplitude levels has a real effect on current results. Analysis of variance on the effect of amplitude on current is shown in table 2.

Table 2. Analysis of variance influence of amplitude on current

Source	DF	Adj SS	Adj MS	F- Value	P- Value
Amplitude	4	0.000145	0.000036	7.04	0.00
Error	145	0.000748	0.000005		
Total	149	0.000893			

From the calculation results, the calculated F value = 7.04 > table F value = 2.43, while the P-value = 0 < 0.05 can be stated to reject the initial hypothesis. From these results, it can be explained that setting different amplitude levels has a real effect on voltage results. The effect of amplitude on voltage results with the initial hypothesis that setting different amplitude levels has a real effect on voltage results. The effect of amplitude on voltage results with the initial hypothesis that setting different amplitude levels has a real effect on voltage results. Analysis of variance on the effect of amplitude on current is shown in table 3.

Table 3. Analysis of variance effect of amplitude on voltage

Source	DF	Adj SS	Adj MS	F- Value	P- Value
Amplitude	4	0.003632	0.000908	7.04	0.00
Error	145	0.018701	0.000129	0.00	
Total	149	0.02233			

From the calculation results, the calculated F value = 7.04 > table F value = 2.43, while the P-value = 0 < 0.05 can be declared reject H0 and accept H1. From these results, it can be explained that setting different amplitude levels has a real effect on voltage results. From these results, it can be explained that setting different amplitude levels has a real effect on voltage results. The effect of amplitude on voltage results with the initial hypothesis that setting different amplitude levels has a real effect on power yield. Analysis of variance on the effect of amplitude on current is shown in table 4.

Table 4. Analysis of variance effect of amplitude on power

Source	DF	Adj SS	Adj MS	F- Value	P- Value
Amplitude	4	0.000	0.00	5.47	0.00
Error	145	0.000002	0.00		
Total	149	0.000002			

From the calculation results, the calculated F value = 5.47 > the table F value = 2.43, while the P-value = 0 < 0.05 can be stated to accept the hypothesis. From these results, it can be explained that different amplitude level settings have a real effect on power results. The previous research has 1: 31 gear ratio and this research has 1 : 13 gear ratio that has larger result than previous research and shows that the gear have significant impact to the current, voltage and power.

Conclusion

The conclusion obtained from this study is that the higher the amplitude, the higher the value of current, voltage and power produced by the single pendulum pontoon model ocean wave power plant. Where the amplitude of sea waves significantly affects the yield characteristics of ocean wave power plants. With F value the count is always greater than with F table and the P-value is smaller by 0.05.

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