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Model of Ocean Wave Energy Converter Based on Water Mass Gravity Force as a Renewable Energy Source

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Abstract *—**The aim of this study was to develop a model of ocean wave energy converter based on water mass gravity force (WEC-WGF) to overcome the flaws of existing wave energy converter that rely on water buoyancy force. This paper presented physical model experiment result of wave energy converter based on water mass gravity force. The harvested energy were compared with calculated theoretical energy based on linear wave theory. The physical model investigation was carried out at wave simulator (flume) in Hydraulics Laboratory Department of Civil Engineering, Hasanuddin University Indonesia on February - March 2016. The physical model consists of a series of one-way gear connected with plastic container as an interface between converter and regular generated wave. Investigation was carried out to observe the influence of gravity weight mass and wave height variations on converters harvested power. The experiment result indicated that the amount of converter Power Take Off (PTO) were strongly influenced by variation of gravity weight mass (M_{gw}), followed by wave height (H) and wave period (T) respectively. These results outperform the calculated power by means of linear wave theory. The result of this experiment could be used as a reference to develop theoretical or analytical model of wave energy converter based on water mass gravity force.***

Keywords— Wave, Gravity Force, Renewable Energy, Wave Energy Converter

I. INTRODUCTION

Energy, water and food are essential needs to support the continuation of human activities. In the last few decades, the main source of energy depends on the burning of fossil fuel. Since the depletion of oil resources, most countries in the world started to realize the importance of environmental conservation and efficient use of fossil fuel reserves. Moreover, the reduction of fossil fuel as a main source of energy hopefully could reduce the level of CO2 emissions which are considered as a main source of global air pollution. The total global CO2 emissions in 2013, comprised of; power plants contribute 42%, transportation 23%, industrial activities 19%, households 6%, services and other sectors produced 3% to 7%. The amount of CO2 released into the atmosphere in the last 42 years increased by approximately 230% from 13.995 million tons in 1971 increased to 32.190 million tons in 2013 [1] [2]. Efforts to reduce CO2 emissions has been carried out through the utilization of renewable energy sources such as wind energy (wind), hydropower plants, solar power, ocean currents and wave energies. In term of energy density, wave energy poses the greatest energy content that is available for 24 hours. However it has not been fully utilize due to the cost per kWh did not economically feasible due to the flaws of existing wave energy converter technologies [3].

The utilization of wave as an energy source have been recognize for long time. For example, the introduction of Wave Motors in Southern California: 1890-1910 but did not develop due to multiple experiment failures [3]. Until the mid-20th century, wave energy has not received much attention. However, as the effect of fuel crisis in 1973-1974, The United States president Richard Nixon presented his idea to find alternative energy sources as an attempt to reduce the dependent on fuel based energy source [4]. From that time, the effort to capture the ocean wave power as a source of renewable energy has attract researchers such as utilizing the up and down movement of waves to drive a hydraulic pump connected to a turbine to rotate the electric generator [5]. Kelly et al [6] proposed a combination of a floating wave power plant with wind power plants to cope the variations in electrical energy produced. O'Cathalin at al carried out the study of the interaction of the waves and converter due to nonlinearity properties of waves using connected buoys were proposed [7].

The buoy vertical movement in harmony with ocean wave was utilize to drive the linear permanent magnet generator [8]. The buoy dimensions effect on efficiency of wave energy converter were studied to determine the most effective float shape to be used in wave energy converter [9]. Wave energy converter must withstand the extreme wave conditions, therefore, Pecher at,al introduced the floating wave energy converter [10]. The prediction of the amount of captured energy by the converter was carried out by means of numerical simulations based on the mathematical models equations in the time domain of regular or non-regular waves [11].

Most of the previous research on wave energy converter mentioned above were rely on ocean wave buoyant force as the prime mover of the wave energy converter. Therefore, the captured power yielded depends on the difference between buoyant force and gravity force of the buoy used. Hence, the efficiency of the existing wave energy converter remains low. This paper presented the new model of wave energy converter that utilized the gravity force instead of buoyant force of water container as a prime source of energy.

II. METHOD AND MATERIALS

II.1. WAVE MODEL

The study of wave energy converter based on water mass gravity force presented in this paper initiated by developing the mathematical approximation model [12]. It was assume that wave poses regular height and period. Therefore, regular ocean wave can be describe as a sine wave with certain amplitude and period. Energy content of ocean wave comprised of potential and kinetic energies [13].

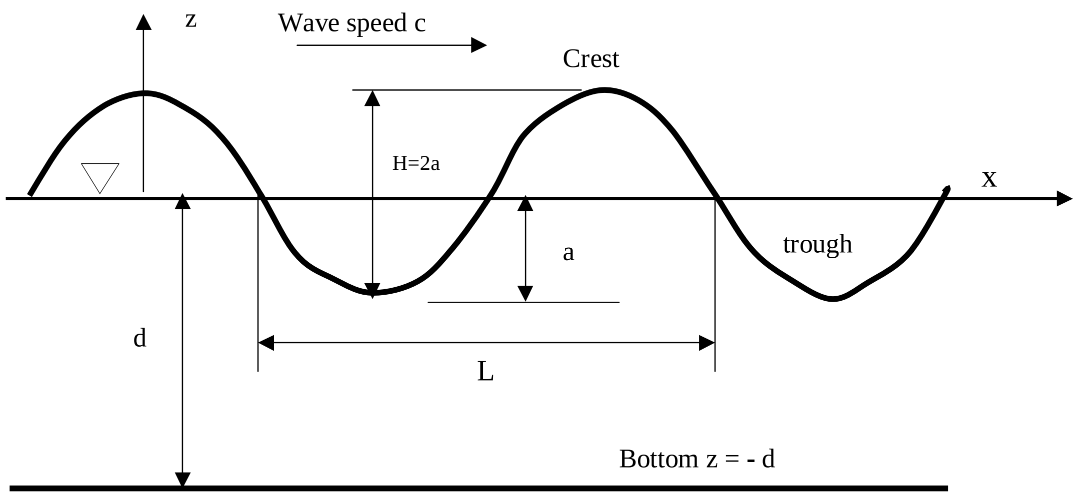

Figure 1. Linier Wave illustration

Wave potential energy,

$$E_p = \frac{\rho g}{4} a^2 \quad \dots\dots (2.1)$$

Kinetic Energy

$$E_k = \frac{\rho g}{4} a^2 \quad \dots\dots (2.2)$$

Total energy

$$E_T = E_p + E_k = \frac{\rho g}{4} a^2 + \frac{\rho g}{4} a^2 = \frac{\rho g}{2} a^2 \quad \dots\dots (2.3)$$

The average energy flow is the rate of change of energy passing per unit length of waves crest through the vertical plane and perpendicular to horizontal propagation/propagation. The energy density is obtained by multiplying the total energy ET with wave speed (group Velocity) Cg [14] hence;

$$P = E_T \, x \, C_g \quad \dots\dots (2.4)$$

$$C_g = \frac{gT}{4\pi} \quad \dots\dots (2.5)$$

$$P = \frac{1}{2} \rho g a^2 . \frac{gT}{4\pi} \quad \dots\dots (2.6)$$

By substituting the distance between the crest and trough where a = H / 2, equation (2.6) can be written

$$P = \frac{1}{32\pi} \rho g^2 H^2 T \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.7)$$

Where:

P = Energy flux (Watt/m)
ρ = Density of sea water (1025 kg / m3)
H = Wave height
T = Wave period

II.2. WAVES AND CONVERTER INTERACTION WORKING PRINCIPLE

The main objective of the wave energy converter presented in this paper is to absorb the ocean wave energy when it moves from the top (crest) to the valley (trough). To realize these goals, then a series of unidirectional gears were use associated with plastic containers filled with water see Figure 2. Since the density of plastic is less then water density of water, then the filled container will partially submerge into water. When the wave oscillates up and down then the container will moves up and down as well.

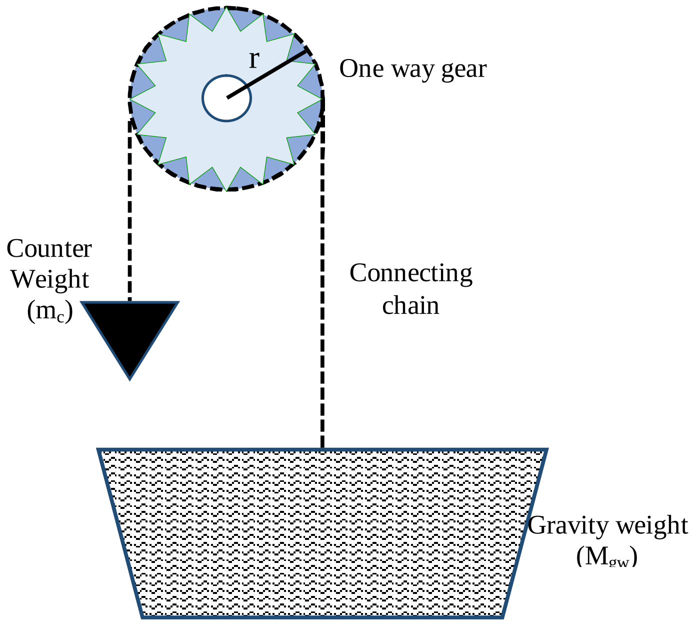

Figure 2 One-way gear gravity-weight pair

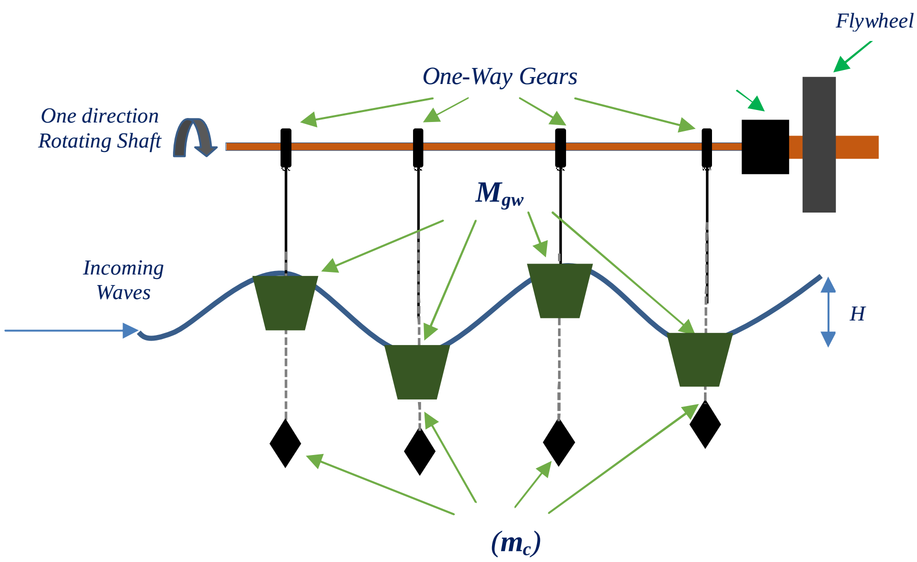

Figure 3 Illustration of wave energy converter based on water mass gravity force (WEC-WGF) [15].

The prime mover of this proposed wave energy converter based on the vertical falling movement of gravity weight illustrated in Figure 2 following the movement of wave from crest to trough. Since the gravity-weight connect with one-way gear then it will rotate the gear in one direction. Furthermore, the up and down movement of the container following the rise and fall of the waves associated with the one-way gear will rotate the shaft converters in a one direction see Figure.3. The proposed model of wave energy converter based on water mass gravity force as illustrated in Figure 3 were investigated using lab scale physical model. The focus of experiment was to compare the measured Power Take Off with the available energy based on theoretical calculation using linear theory of regular wave Equation 2.7. The variable consist of dependent independent variables. Power Take Off produced by converter was set as a dependent variable while gravity-weight mass, wave height, wave period, gear spacing and number of gravity weight are the dependent variables. However, gravity weight mass is the focus of this research. Therefore, the experiment result presented in this paper was limited to the effect of gravity weight mass variation on the amount of power produce by proposed converter compare with calculated power using wave linear theory.

II.3. EXPERIMENT SET UP

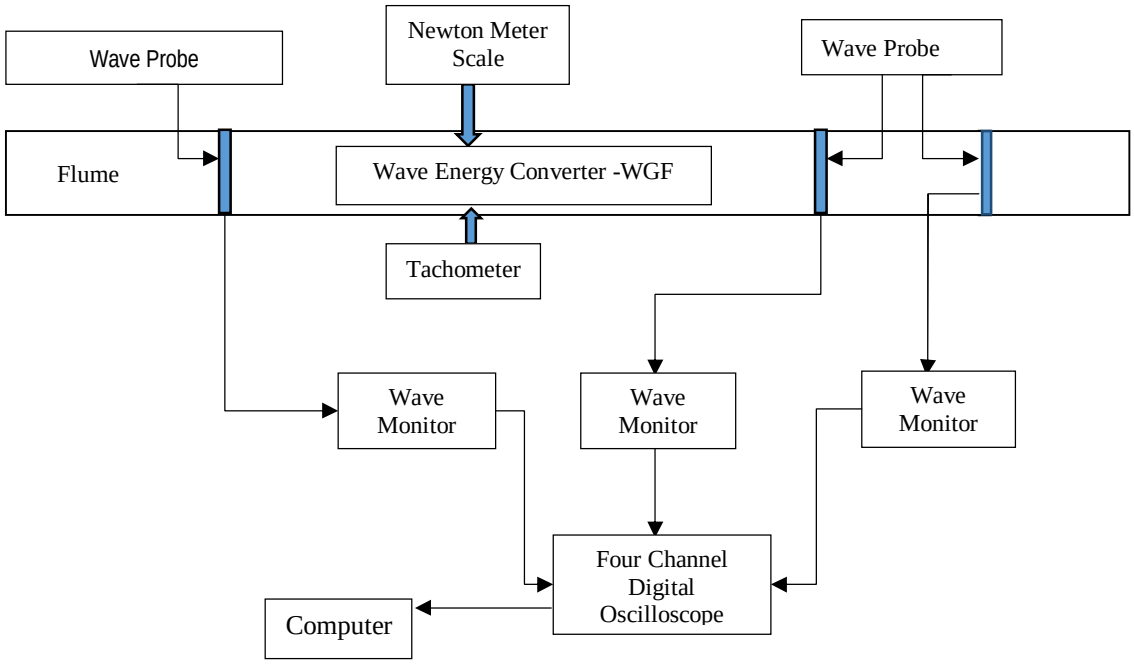

Figure 4 Block diagram of WEC-WGF model experimental set-up [1]

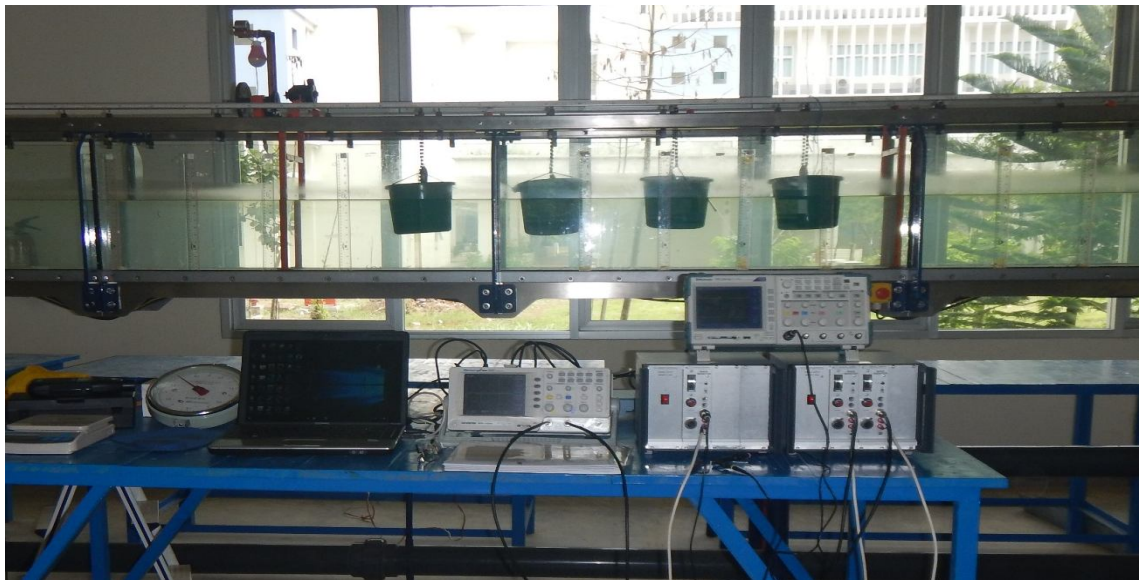

Figure 5. Lab Scale Wave Energy Converter-WGF

The experiment of WEC-WGF model using regular wave was conducted at Hydraulic Laboratory, Department of Civil Engineering Hasanuddin University Indonesia. In this experiment, there were three variables was investigated as independent variables that comprised of, wave height, wave period and gravity weight mass variations respectively. The acquisition of wave parameters and converter output power were measured using wave probe, Digital Tachometer and Newton Meter scale respectively. The instrument was set-up as described in Figure 4. There were three wave probe were used. The first two probe were place right in front of the converter. The third probe was placed at the rear of the converter. These wave probes were aimed to measure the wave height, periods and length respectively. The third was used to measure the wave height since the wave period did not change after interacting with the converter.

The output power captured by the converter were calculated based on flywheel radial speed (RPM) and flywheel torque (Nm). The RPM data was captured by digital Tachometer and torque was measured by means of Newton meter scale. Power (watt) is the product of RPM times Torque divided by 9550 [16]. The calculated power were compared with simulated wave power using wave linear theory Equation 2.7. [17] [18].

II. RESULT AND DISCUSSION

The focus of this paper is to present the effect of gravity weight mass variation on the output power of the proposed wave energy converter based on water mass gravity force while the other parameters were set at fixed value. The experiment parameters that adjusted at fixed variable value consist of wave length L = 160 cm, water depth of 25 cm, counter weight mass 0.328 Kg, wave period T = 1.2 seconds, spacing between one way gear (G_s) = 40 cm and wave height (H) =7 cm. The gravity-weight mass was varied from 1.0 Kg up to 4.5 Kg. Gravity weight container dimension is 28.5 cm x 23 cm.

Tabel 3.1 Experimental results of gravity weight mass variation

Gravity weight Mass (kg)	Counter Weight Mass (kg)	Flywheel radial speed (RPM)	Torque (Nm)	Measured Power (Watt)	Calculated Power of Linear Theory	Power Ratio
1.5	0.328	147	1.5	23.09	0.2020	114.32
2.0	0.328	162.1	2.5	42.43	0.2020	210.11
2.5	0.328	162.2	3	50.95	0.2020	252.28
3.0	0.328	182.1	3.5	66.74	0.2020	330.44
3.5	0.328	196.7	3.7	76.21	0.2020	377.33
4.0	0.328	193.5	4	81.05	0.2020	401.29
4.5	0.328	204.4	4.5	96.31	0.2020	476.88
5.024	0.325	191.8	5.5	110.46	0.2020	546.92

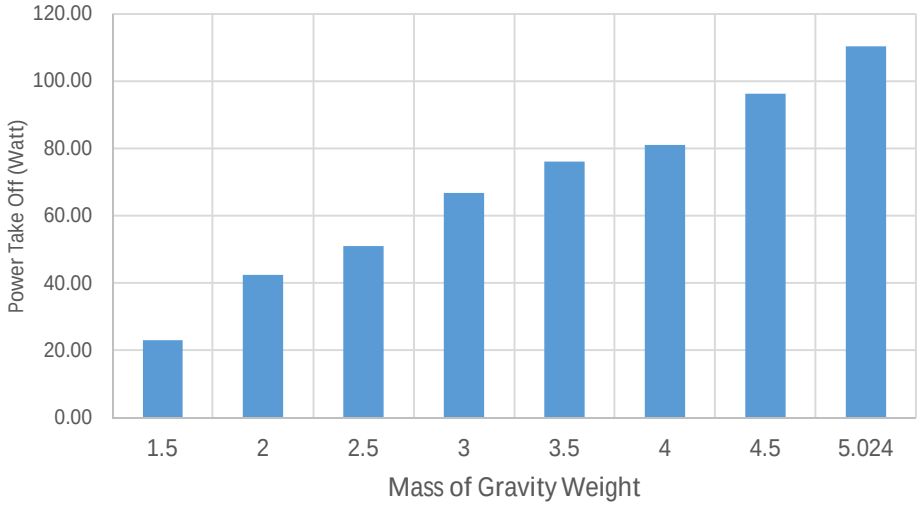

Figure 6 Relationships between gravity weight mass and converters harvested energy

The output power based on direct measurement flywheel radial speed (RPM) using Digital Tachometer and flywheel shat by means of Newton meter scale presented in Table 3.1. It was found that variation of gravity weight mass has less effect on radial speed. On the hand, the flywheel torque was linearly follow the increment of gravity weight mass change. Therefore, the converter output power as the product of RPM and torque showed linear increment see Figure 6. Furthermore, data obtained in this experiment were calculated using linear wave theory formula Equation 2.7. This formula require wave height and period data as input parameters. All data was converted into international standard to avoid the scaling effect. In this case, the acquired wave height data was changed into meter unit. Since the linear theory did not consider the effect of water mass then the calculated power using its formula was very small compared to captured power using the proposed wave energy converter. The output power ratio range from 114.32 up to 546.92 times see Table 3.1.

The principle finding of this study was the proposed wave energy converter does not rely solely on wave height and period as the existing WECs. However, the proposed converter was capable to convert the water mass into renewable energy. This principle was proved by laboratory experiment. Therefore, it is possible to tap unlimited amount of renewable energy from ocean waves using the principles developed in this proposed wave energy converter. Moreover, this is just the infancy stage on laboratory experiment. Information about the maximum dimension of gravity weight and shape need further studies. The principle finding was valid for regular wave in wave flume. Therefore, it requires further studies under irregular waves and real seas environment.

The result of this proposed converter model could be used to develop the more mature theoretical model of wave energy converter based on water mass gravity force. However, this finding tell us that it is possible to capture sufficient energy even at the low ocean wave. Moreover, at the same wave height and period it is possible to capture different amount power of harvested wave energy.

III.CONCLUSION

The proposed wave energy converter does not rely solely on wave height and period since the introduction of water mass gravity force. The proposed converter has the capability to capture the water mass vertical movement to be converted into renewable energy. Therefore, it is possible to harvest unlimited amount of energy from ocean waves using the proposed wave energy converters principle. This finding tell us that, it is possible to capture sufficient energy even at the low ocean wave site. Moreover, at the same wave height and period it is possible to capture different amount power. The converter output power was outperform the calculated theoretical power using linear wave energy theory. However, this finding just in the infancy steps which based on laboratory experiment result under regular wave environment. Information about the maximum dimension of gravity weight and its efficient shape remain unanswered. Therefore, more work is required to develop wave energy converter based on water mass gravity force under irregular wave or real seas environment.

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REFERENCES

[1] M. Muchtar, S. Manjang, D. A. Suriamihardja and M. A. Thaha, “Physical Model Performance of Wave Energy Converter Based on Water Mass Gravity Force under Container Shape Variation,” *International Journal of Science and Research (IJSR),* vol. 5, no. 9, pp. 1627 - 1630, 2016.

[2] International Energy Agency, “ CO2 EMISSIONS FROM FUEL COMBUSTION Highlights,” International Energy Agency, Paris, France, 2015.

[3] C. Miller, “A Brief History of Wave and Tidal Energy Experiments in San Francisco and Santa Cruz,” 2004 . [Online]. Available: http://www.outsidelands.org/wave-tidal3.php. [Accessed 12 September 2014].

[4] US Public Affair, “US Department of State Office of the Historian,” 31 October 2013. [Online]. Available: http://history.state.gov/milestones/1969-1976/oil-embargo. [Accessed 12 September 2014].

[5] R. H. Hansen, M. M. Kramer and E. Vidal, “Discrete Displacement Hydraulic Power Take-Off System for the Wavestar Wave Energy Converter,” *Energies*, vol. 6, no. 8, pp. 4001- 4044, 2014.

[6] T. Kelly, T. Dooley, J. Campbell and J. V. Ringwood, “Comparison of the Experimental and Numerical Results of Modelling a 32-OscillatingWater Column (OWC), V-Shaped Floating Wave Energy Converter,” *Energies*, vol. 6, no. 8, pp. 4045-4077, 2013.

[7] M. O´Cathalin, B. J. Leira, J. V. Ringwood and J.-C. Gilloteaux, “A modelling methodology for multi-body systems with application to wave-energy devices,” *Ocean Engineering,* vol. 35, no. 13, p. 1381– 1387, 2008.

[8] M. Eriksson, J. Isberg and M. Leijon, “Hydrodynamic modelling of a direct drive wave energy converter,” *International Journal of Engineering Science,* vol. 43, no. 17-18, p. 1377–1387, 2005.

[9] S. Bozzi, A. M. Miquel, A. Antonini, G. Passoni and R. Archetti, “Modeling of a Point Absorber for Energy Conversion in Italian Seas,” *Energies,* vol. 6, no. 6, pp. 3033-3051, 2013.

[10] A. Pecher, J. P. Kofoed and T. Larsen, "Design Specifications for the Hanstholm WEPTOS Wave Energy Converter," *Energies*, vol. 5, no. 4, pp. 1001-1017, 2012.

[11] A. Wacher and K. Neilsen, "Mathematical and Numerical Modeling of the AquaBuOY Wave Energy Converter," *Mathematics-in-Industry Case Studies Journal*, vol. 2, pp. 16-33, 2010.

[12] J. B. Herbich, "LINEAR WAVE THEORY," 2015. [Online]. Available: http://www.globalspec.com/reference/63553/203279/linear-wave-theory. [Accessed 11 November 2015].

[13] J. Falnes, "Wave Transport of Energy and Momentum," in *Ocean Waves and Oscillating Systems*, Cambridge, Cambridge University Press, 2004, pp. 75-77.

[14] L. E. Assis, A. Beluco and L. E. B. d. Almeida, "On the wave energy potential along the southern coast of Brazil," *International Journal of Energy and Environment*, vol. 5, no. 1, pp. 59-66, 2014.

[15] Masjono, S. Manjang, D. A. Suriamiharja and A. Thaha, "MODELLING OF ONE WAY GEARS WAVE ENERGY CONVERTER FOR IRREGULAR OCEAN WAVES TO GENERATE ELECTRICITY," *Jurnal Teknologi*, vol. 78, no. 5-7, pp. 37-41, 2016.

[16] WEN Technology, "UNIPOWER," WEN Technology, 2002. [Online]. Available: http://www.wentec.com/unipower/calculators/power_torque.asp. [Accessed 18 8 2016].

[17] Masjono, S. Manjang, Z. Zainuddin and M. A. Thaha, "Modelling and Numerical Simulation of a Series of One Way Gears Wave Energy Converter to Generate Electricity," Kuta. Bali, 2014.

[18] Masjono, "Desain dan Simulasi Konverter Energi Gelombang Laut sebagai Pembangkit Tenaga Listrik," *JURNAL ILMIAH ELITE ELEKTRO*, vol. 3, no. 2, pp. 113-118, 2012.

