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Damping Effect Coupled with the Internal Translator Mass of Linear Generator-Based Wave Energy Converters

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Abstract: The damping effect, induced inside the linear generator, is a vital factor to improve the conversion efficiency of wave energy converters (WEC). As part of the mechanical design, the translator mass affects the damping force and eventually affects the performance of the WEC by converting wave energy into electricity. This paper proposes research on the damping effect coupled with translator mass regarding the generated power from WEC. Complicated influences from ocean wave climates along the west coast of Sweden are also included. This paper first compares three cases of translator mass with varied damping effects. A further investigation on coupling effects is performed using annual energy absorption under a series of sea states. Results suggest that a heavier translator may promote the damping effect and therefore improve the power production. However, the hinder effect is also observed and analyzed in specific cases. In this paper, the variations in the optimal damping coefficient are observed and discussed along with different cases.

Keywords: wave energy converter; linear generator; damping; translator mass

1. Introduction

Wave energy converters (WECs) are power plants that convert the kinetic energy from ocean waves into electricity. Relevant research can be dated back to the late 1890s, and nowadays varieties of WEC concepts have developed into prototypes tested in laboratory environments or even at larger scales deployed offshore. WEC technologies are classified in a series of published review documents [1–3]. The criteria to categorize WECs include the mechanical mechanism, installed location, power-take-off (PTO) system, etc. [4]. One categorization method was proposed in light of the working principal of WECs. In [5], WECs are classified into three types: (a) oscillating water column (OWC) [6]; (b) oscillating (activated) body [7]; (c) overtopping device [8]. In this paper, the studied WEC is referred to as one subcategory, classified as a point absorber of (b), the activated body. Activated bodies transfer the motion of ocean waves to drive the internal motion of the WEC. As a subcategory of activated body, the main feature of point absorbers is that the floaters, designed to absorb wave energy, are relatively small in the horizontal dimensions compared to the length of the waves. A variety of mechanisms are available for point absorber devices to achieve energy conversion, such as hydraulic system and linear generator. For hydraulic systems, fluid power is converted from absorbed wave energy to drive the hydraulic motor and further induction generator to produce electricity. For the other mechanism, linear generators convert mechanical energy from ocean waves directly into electricity by driving the translator to reciprocate in a linear generator.

The linear generator-based WEC proposed in the paper was invented in the wave power project at Uppsala University [9]. In the project, the WEC concept was designed with two major mechanical parts. One was a permanent magnet linear generator [10], connected to another part, a floating buoy, to extract energy from ocean waves [11]. Thus far, around 20 prototypes have been manufactured and installed at the test site [7,12,13]. The WECs function as scientific platforms for further multidisciplinary research topics, including hydrodynamic studies, WEC design, electrical connection, environmental impact, biofouling, and so on [14]. While aiming to optimize WEC performance, several control techniques were installed and tested under the capricious ocean environment.

Optimization of WEC conversion efficiency has been a main topic of research. A number of working mechanisms have led to a large variety of control techniques [15]. The WEC concept from Uppsala University employs a direct drive linear generator as its power-take-off (PTO) system, and the design facilitates the internal damping coefficient to play a significant role in energy absorption as well as energy conversion [16]. Together with the velocity of the linear generator, the damping coefficient decides the damping force and further determines the performance of WECs [17]. Therefore, optimal strategies for damping control have been a research focus to optimize power generation, such as the different controls given in [18]. The damping coefficient is vital in the study of damping control [19]; however, some mechanical parameters, especially the internal translator mass, also affect the damping and even hydrodynamic behavior of the translator [20]. Another factor is the impact of wave climates on WEC performance. Since the environmental impact is frequently neglected due to its complex impact on the hydrodynamic behavior of WECs [21], the influence of climate is a vacancy of knowledge in evaluating the performance of WECs under the wave climates at specific ocean regions.

The work presented in this paper studies the damping effect coupled with translator mass under the wave climates along the west coast of Sweden as a case study. The novelties of this paper can be summarized as follows: firstly, translator mass is studied by varying the damping effect on power production. Secondly, the influence of translator mass on annual energy production is investigated under real wave climates. The paper is organized as follows. Section 2 describes the hydrodynamics of the WEC system interacting with ocean waves. Subsequently, research materials are provided for numerical models, including the wave climates at research site and the WEC configuration. Section 3 outlines the results and discusses the various power profiles contributed by different settings of translator mass. The comparisons are analyzed based on annual energy production under wave climates at the research site. In Section 4, the studies are concluded and future work is considered.

2. Materials and Methods

2.1. Energy Capture Theory

The linear generator-based WEC consisted of two movable objects, a buoy and a translator. The buoy floated on top of the waves and followed the wave motion. The generator was placed at the seafloor. In the generator, the movable translator was tethered to the buoy via a guiding line, as illustrated in Figure 1. The buoy was restricted to heaving motions. The buoy/wave interaction was modeled by the linear potential wave theory. The time-dependent vertical position for the buoy and translator were denoted as $x_b(t)$ and $x_t(t)$, respectively. The motion of the buoy and the translator are described by two coupled ordinary differential equations [12] (see Equation (1)):

$$(m_b + m_\infty)\ddot{x}_b = f_e(t) - f_r(t) - f_h - f_l(x_b, x_t) \quad (1)$$

Equation (1) describes the buoy motion, where m_b is the mass of the buoy, m_∞ is the added mass in infinity, f_e is the excitation force, $k(t)$ is the impulse response function for the radiation impedance, f_h is the hydrostatic stiffness, and f_l is the line force. Moreover, $f_r(t)$ is the radiation force computed by a direct integration of the convolution integral approach as $f_r(t) = \int_{-\infty}^t \dot{x}_b(t_1)k(t-t_1)dt_1$. The hydrodynamic parameters for the excitation force, radiation impedance, and added mass were pre-calculated by the commercial software WAMIT [22].

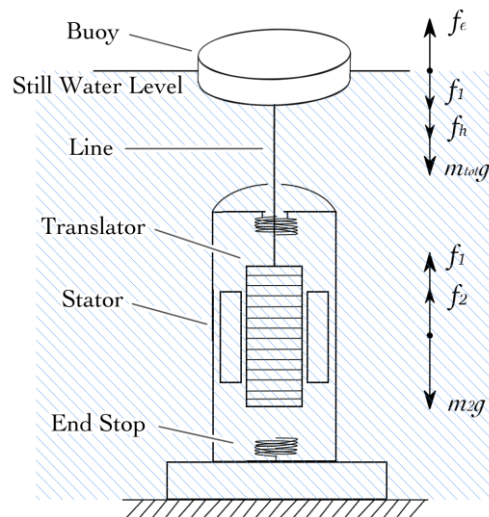


Figure 1. A basic mechanical structure of the studied wave energy converter (WEC) device showing the force diagram on the right side of the WEC.

Equation (2) represents the motion for the translator, where m_t denotes the translator mass and f_t denotes the generator damping force:

$$m_t \ddot{x}_t = f_1(x_b, x_t) + f_t(x_t) - m_t g \quad (2)$$

Equation (1) and Equation (2) both represent the interaction between the waves and the WEC. To solve Equation (1) and Equation (2), semi-implicit Runge–Kutta time integration methods of different orders are used. In addition, the guiding line is modeled as a spring, i.e., the line force is proportional to the line extension; see Equation (3), where c_1 is the spring constant of the line:

$$f_1(x_b, x_t) = \begin{cases} c_1(x_b - x_t) & \text{if } x_b > x_t \\ 0 & \text{else} \end{cases} \quad (3)$$

The generator damping is modeled as a liner damper (Equation (4)), where c_2 is the damping coefficient. Equation (4) is of significance in this paper, as it suggests the relationship between the generated electrical power and the damping effect in the study:

$$f_t(\dot{x}_t) = -c_2 \dot{x}_t \quad (4)$$

In the paper, the concept of capture width ratio (CWR) is also proposed. CWR defines the relationship between the average absorbed power and the power transported towards the buoy [23]. The expression for the capture width ratio is given by:

$$CWR = \frac{P_{\text{absorbed}}}{D \cdot P_{\text{available}}} \quad (5)$$

where P_{absorbed} is the average absorbed power of the buoy, and the buoy diameter is denoted by D . In this study, the average absorbed power was investigated by WEC modeling. According to the condition of the waves in deep water, $P_{\text{available}}$ is given by:

$$P_{\text{available}} = \frac{\rho g^2}{64\pi} T_e H_s^2 \quad (6)$$

In Equation (6), T_e is energy period and H_s is significant wave height. The equations above are described and solved in the time domain.

2.2. Numerical Modeling of the Wave Energy Converter

2.2.1. Research Site and Model Configuration

The data sets of ocean wave climates were collected at the research site along the west coast of Sweden [24,25]. All the sea states displayed in Figure 2 were used as inputs to the WEC model [26]. By modeling the WEC, a matrix of converted electrical power was attained according to each sea state in the matrix [27]. Additionally, the annual energy production at Test Site 6, as marked in Figure 3, can be calculated by multiplying the power matrix with the static hours for each sea state. Optimal damping is only valid as a reference in the case of Site 6.

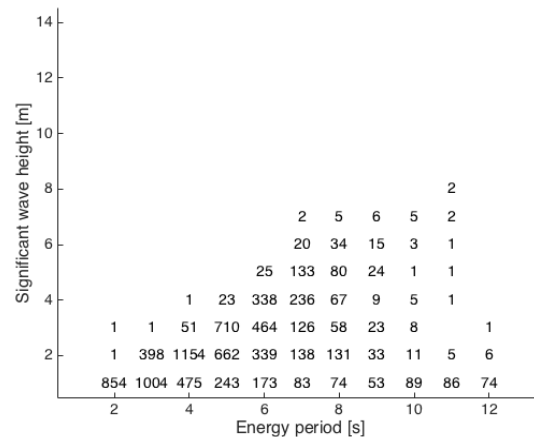


Figure 2. A scatter matrix of the annual occurrence for the sea states at Site 6. Numbers give average occurrence in hours per year.



Figure 3. Map presenting the locations of the studied sites. In the study, the data for wave climates at Site 6 were utilized.

2.2.2. Model Configuration of the Wave Energy Converter

A numerical WEC model was built up in terms of the hydrodynamic theory [28], as described in Section 2 [29]. The purpose for the model is to predict the energy absorption by WEC simulation in both ideal and realistic wave climates. The model is an important platform for further control studies in order to enhance the conversion efficiency. A set of parameters for the WEC is found in Table 1. In the WEC model, a cylinder buoy is connected with the linear generator model [30].

Table 1. WEC specifications.

Parameter	Value
Vertical stator length, l_s (mm)	2000
Vertical translator length, l_t (mm)	2000
Translator mass, m_t (kg)	2700
Air gap, l_{ag} (mm)	3
Pole width, l_p (mm)	50
Generator resistance, R_g (Ω)	$1 \pm 1.5\%$
Generator inductance, L_g (mH)	20
Spring coefficient for upper end stop, k_u (kN/m)	243
Spring coefficient for lower end stop, k_l (kN/m)	215
Buoy diameter, D (m)	4
Buoy mass, m_b (kg)	6300
Damped natural frequency, ω_0 (rad/s)	2.2

2.2.3. Model Configuration of the Wave Energy Converter

The wave data sets consisted of irregular waves where the wave elevation was a function of time. These data sets were produced by superimposing harmonic waves where the amplitude of each harmonic component was related to the two parameter Bret–Schneider spectrum and the phase shifts between the components were chosen randomly. Figure 4 gives the hydrodynamic parameters of excitation force, added mass, and radiation resistance of a buoy under an irregular wave with significant wave height of 0.75 m and energy period of 3.5 s. Figure 5 provides a section of time-based data presenting the position and velocity of the buoy and translator respectively under the regular wave with a significant wave height of 0.75 m and an energy period of 3.5 s. As the distance between the absorber and generator was not fixed, slackness in the guiding line occurred. As the guiding line was regarded as an ideal elastic spring in this study, the peak loading was not considered, even though it is an important parameter in the mechanical design of WEC systems, and it will be included in future studies.

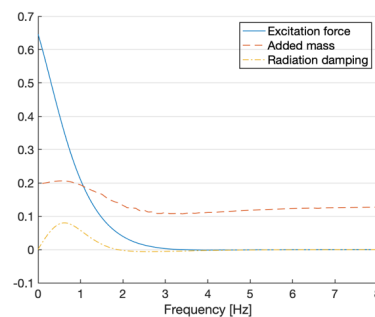


Figure 4. The following hydrodynamic coefficients contributed to the wave input: non-dimensionalized surge on excitation force and added mass and heave coefficients of radiation resistance.

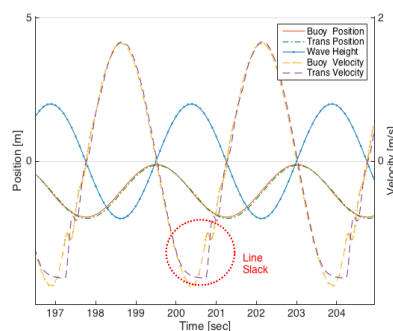


Figure 5. Hydrodynamics for the buoy and translator under harmonic waves. In the figure, slack is shown to occur in the guiding line between the buoy and the translator.

2.3. Research Object

A series of power profiles can be obtained by varying the damping coefficients coupled with different settings of translator mass. The translator mass plays an important role in damping in the linear generator and it also affects the buoy system when absorbing and transferring the mechanical energy to the translator. The purpose of this study on translator mass is to investigate the relevant impacts on WEC power production by varying the damping coefficient.

Three settings of mass (2500 kg/5000 kg/10,000 kg) were chosen for the investigation. The reason for these settings was to give references for the practical possibility to construct the translator within the range of these mass values in future studies. A 10,000 kg translator is much heavier than the 6300 kg buoy. Hereby, the heavier translator mass leads to a higher inertia and further a demand for higher excitation force to drive to move, comparing with the other two options. Additionally, a higher translator mass might contribute to more complicated system dynamics. According to Equation (1), there might be impact on velocity of the translator, radiation force, and the occurrence of line slackness. In this case, it was a useful reference to observe the consequence of a WEC with a heavier mass interacting with specific wave climates.

Three identical irregular wave sources, (3.5 s, 0.75 m), (6.5 s, 0.75 m), and (6.5 s, 2.75 m), were initially utilized to compare all the mass settings. Three power profiles were consequently obtained from the WEC model. Note that the translator mass was independent from the electromagnetic performance of the generator, despite its contribution to acceleration that also influences the mechanical motion of the translator. In addition, the mechanical losses, mainly friction in the wheels of the translator, were neglected in this study.

A matrix of annual energy was obtained under real wave climates at the research site. The overall annual impact on WEC performance was observed with different settings of translator mass. Site 6 gave the typical annual wave climates offshore the west coast of Sweden. Power and energy matrixes were obtained and the elements of the matrix varied regarding the three translator masses. In the model, the damping coefficient was kept constant for each simulation, with incident waves of 10 min. The simulation length was investigated in [31], and the results proved that 10 min was feasible in this study for the WEC. The aim of this study was to resolve what combination was mostly optimized for energy absorption under typical annual wave climates. Note that some figures and data in this research are also provided in [32].

3. Results and Discussion

3.1. Damping Effect Coupled with Varied Translator Mass

In terms of the hydrodynamics depicted in Equation (1), the damping coefficient was decisive for electrical energy generation. Three cases with varied sea states were chosen: (0.75 m, 3.5 s) in Figure 6a, (0.75 m, 6.5 s) shown in Figure 6b, and (2.75 m, 6.5 s) in Figure 6c. The use of these three cases depended on the configuration of the WEC design. Furthermore, it depended on (i) the case (3.5 s, 0.75 m) representing a typical wave climate at Site 6, containing most of the wave occurrence at the test site; (ii) the case of Figure 6b, which was also a typical wave climate that contributed a high portion of the annual energy production, while Figure 6c was a powerful sea state for a test site. Thus, these three wave climates were utilized as the representative case studies for the effect on the translator mass. In the study, in light of the WEC configuration, three typical translator masses were determined to investigate the coupled effect on power output by the translator mass and damping coefficient. This model was tested with three different cases of translator mass under three identical sea states.

The average power generated from the WEC with respect to the applied damping is shown in Figure 6. The power profiles were similar to the curve pattern. The power production enhanced and reached a peak value as the damping coefficient increased from the lowest values. Table 2 lists

the values of maximum average power and the corresponding optimal damping coefficient for each mass setting.

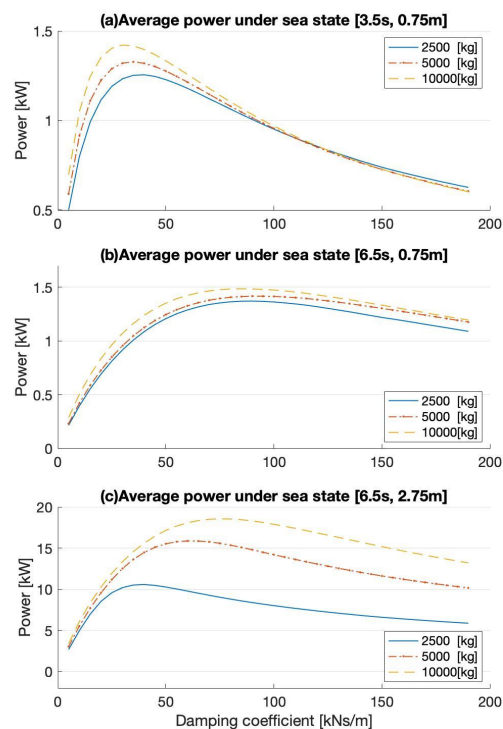


Figure 6. The average captured power in response to the damping coefficient with three different translator masses, 2500 kg/5000 kg/10,000 kg. The profiles were obtained under three sea states: (a) (3.5 s, 0.75 m); (b) (6.5 s, 0.75 m); (c) (6.5 s, 2.75 m).

After an initial increase in power production with increased damping, the power profile showed a downward trend. In fact, the power even decreased lower than the power of the initial values of the damping coefficient. In Figure 6a, a dramatic downward trend of the profiles is shown for the three cases. When the damping coefficient was over 100 kNs/m but less than 200 kNs/m, the power output for the 10,000 kg case declined to a lower level than for 2500 kg. This is because the damping force might inversely affect the movement of the translator, i.e., the damping force gets too high; thus, the actual excitation force cannot meet the demand to drive the translator. The higher mass also means higher excitation force compared to the other cases; otherwise, the low excitation cannot drive the translator to produce electricity.

Table 2. The optimal damping coefficients and corresponding power production as a function of translator mass.

(a) $T_e = 3.5$ s, $H_s = 0.75$ m		
Translator Mass (kg)	Optimal Damping Coefficient (kNs/m)	The Average Power for the Optimal Damping (kW)
2500	35	1.08
5000	40	0.98
10,000	30	0.96
(b) $T_e = 6.5$ s, $H_s = 0.75$ m		
Translator Mass (kg)	Optimal Damping Coefficient (kNs/m)	The Average Power for the Optimal Damping (kW)
2500	45	9.01
5000	55	10.02
10,000	85	10.34

A translator with small mass can also cause spikes in line force. The spikes might be due to the snap loads. For example, if the translator is pulled to its highest position, but then falls with a lower velocity than the buoy, a slack will occur in the line between the buoy and the translator. When the buoy moves upwards, but the translator keeps moving downwards, a snap occurs due to the sudden tightening of the line. The snap will cause a high momentary force, and probably harm the WEC system. The occurrences of snap load may be one of the main reasons for less energy absorption by the buoy. If the frequency of snap loads is high, it will seriously hinder proper performance of the WEC system. Thus, it is of significance to further study the frequency of snap loads.

The observed results in Figure 6 are valid for the case of linear electrical damping with a circular buoy of 4 m in diameter. Other buoy sizes and shapes, and other damping strategies, produce different results, though this is not within the scope of this study. Although the optimal damping values are visible in the figure, it should also be noted that the curves are asymmetric. This is due to the insufficient discretization on the spectrum. The shape would probably be improved if more samples with a longer simulation time are measured, or more sea states were included in the study.

The impact from the translator mass differed in response to varied sea states. For the case of (3.5 s, 0.75 m), the linear generator with a 2500 kg translator gained the highest amount of power production. The absorbed power for 5000 kg and 10,000 kg did not differ much. For the other case (6.5 s, 2.75 m), the linear generator with the 2500 kg translator gained the lowest level of power production among the three cases. In addition, the maximum power for the 10,000 kg case was not much higher than that for the 5000 kg case. Further investigations with results are presented in Figure 7.

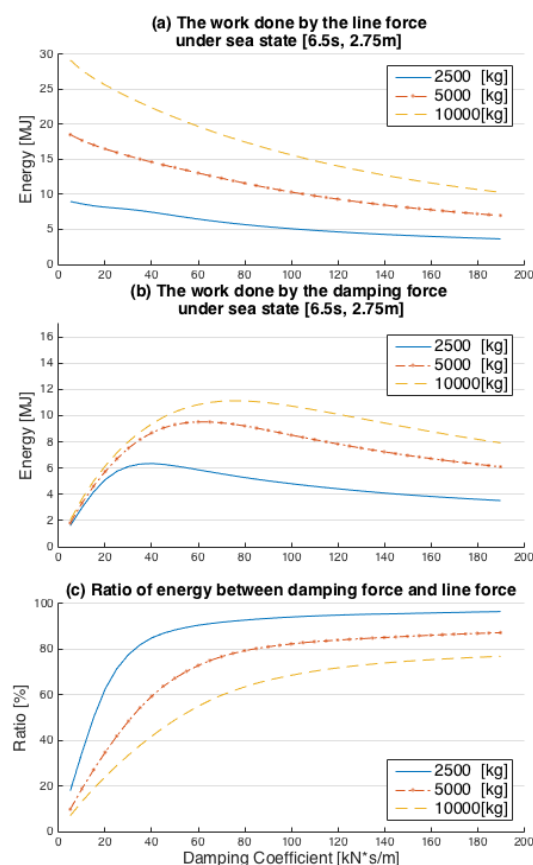


Figure 7. The converted energy of the WEC under sea state (6.5 s, 2.75 m), with a variation of damping coefficients from 5 kNs/m to 190 kNs/m: (a) energy dissipated in the absorbing process through the line; (b) energy absorbed by the generator for conversion; (c) the ratio of energy converted from the buoy to the generator.

In both Figures 6 and 7, it can be observed that energy was dissipated on the buoy into the ocean through the guiding line. The dissipated energy was much higher compared to the energy absorbed by the damping force. Moreover, less energy was dissipated on the buoy as damping coefficient increased, i.e., there was more wave energy absorbed and converted into electrical energy. As the guiding line was regarded as an ideal spring, the energy was not dissipated through the line. Instead, the energy was carried away mainly by the radiation on the buoy when constrained by the line. Additionally, the impact of hydrodynamics varies the system dynamics due to different translator mass. The results suggest that a heavier translator leads to higher energy dissipation by radiation on the buoy. In this case, a proper translator mass should be included in the WEC's design by considering the impact of radiation on the buoy.

A comparison is shown in Figure 8 with the instantaneous powers for the three cases of translator mass. The output power was obtained under the sea state of (3.5 s, 0.75 m) within 10 min. Higher instantaneous power was observed with higher translator mass, resulting in a higher average power. According to the results shown in Figures 6 and 7, it is necessary to include more details in future works to investigate the conversion efficiency for a WEC.

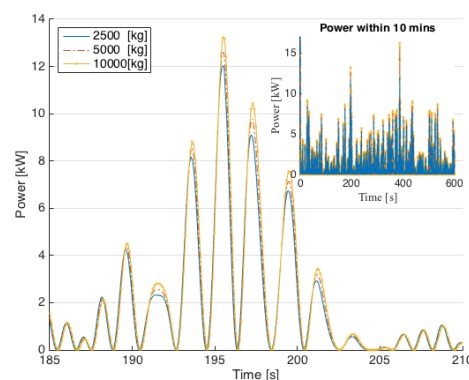


Figure 8. Instantaneous power output with different cases of translator mass under an identical sea state (3.5 s, 0.75 m). The main plot gives the comparative results in a time span of 25 s, while the sub-plot gives an overview of the results in 10 min.

3.2. Coupled Impact on WEC Performance

3.2.1. Annual Energy Production

A matrix of the annual energy production was achieved by multiplying the scatter diagram of Figure 2 with the energy matrix of Figure 9, as shown in Figure 10. By adding all the values for each sea state, the annual energy at Site 6 was 22.57 MWh in total. A matrix of the percentage of the annual energy delivered for each sea state is presented in Figure 10. This result was valuable if engineering or economic challenges placed limitations on the generator design. In particular, it was observed that the sea state (5.5 s, 1.75 m) contributed the most (13.11%) to the annual energy production.

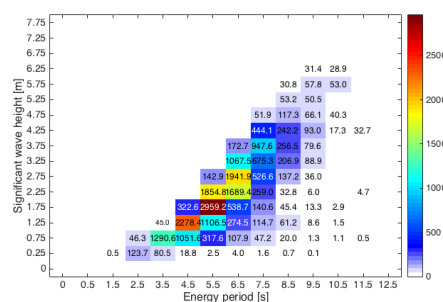


Figure 9. Annual energy production in kWh at Site 6 with a damping coefficient of 60 kNs/m. The red square at (5.5 s, 1.75 m) gives the highest percentage among all the sea states.

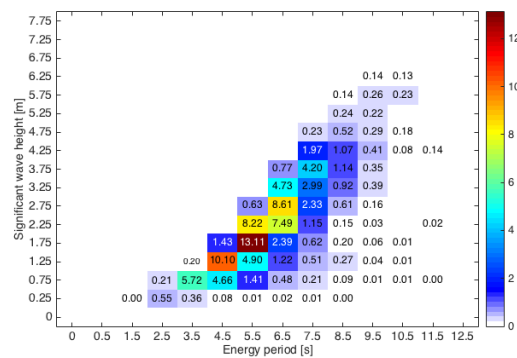


Figure 10. Annual energy conversion in % delivered for each sea state occurrence at Site 6. The red square at (5.5 s, 1.75 m) gives the highest percentage among all the sea states.

In terms of the studied wave energy technology, it is reasonable that sea states with more wave energy should result in greater energy absorption. These sea states, however, have a relatively low annual occurrence from the perspective of annual energy production. The least powerful sea states, although very common, also contribute only to a small degree to the annual energy production because of the small energy contained in these sea states (Figures 9 and 10).

The annual energy production was obtained by choosing a damping coefficient (60 kNs/m) that was good for most sea states based on the earlier results. The results show that the sea state that contributed most (over 13%) to the annual energy production was at around (4.5 s, 1.25 m). Table 3 gives a list of the sea states with high percentages from an annual energy perspective. From Figure 10 it can be observed that sea states with wave heights between 0.75 to 2.75 m and wave periods from 3.5 to 6.5 s contributed almost 54% of the annual energy production. This is important information to consider when designing WEC components, such as the stroke length, and further designing a proper control strategy.

Table 3. A list of most-contributed wave climates to the overall energy production.

Order	Wave Period (s)	Wave Height (m)	Annual Energy Production (MWh)	Percentage (%)
1	5.50	1.75	2.96	13.11
2	4.50	1.25	2.28	10.10
3	6.50	2.75	1.94	8.61
4	5.50	2.25	1.85	8.22
5	6.50	2.25	1.69	7.49
6	3.50	2.75	1.29	5.72

3.2.2. Annual Energy Production with Varied Translator Mass

Previous results hint at a significant impact of the translator mass on the power production. The impact depends on the wave climate, demonstrating that heavier translators do not definitely lead to higher power production. Taking the sea state (3.5 s, 0.75 m) as an example, the generator with a 2500 kg translator actually absorbed the highest energy, meaning that when the WEC is working under a gentle wave climate, a lighter translator contributes to a higher wave power absorption compared with the heavier translator. The reason for this is that a higher excitation force is necessary to drive the heavier translator while the lighter translator demands lower excitation force. Hence, the heavier translator of 10,000 kg results in less power production due to the insufficient excitation force from small waves. The same reason can also explain why a generator with a 10,000 kg translator obtained the highest power production in the case of (6.5 s, 2.75 m). The heavier translator has the advantage of obtaining more power absorption under huge waves. Furthermore, as a typical case for the test site, the wave climate (6.5 s, 2.75 m) has a significant role in the annual energy contribution. However, the 10,000 kg translator did not show much competitiveness compared to the 5000 kg

translator. Therefore, more consideration should be taken with other environmental conditions when designing the mass of the translator.

Comparisons among the three cases were further performed under the wave climates at Site 6. The red line in Figure 11b gives the boundary where the lower part with the 5000 kg translator contributed less power than the 2500 kg translator. The violet line in Figure 11c also gives a boundary showing that the lower part with the 10,000 kg translator contributed less power than the 5000 kg translator.

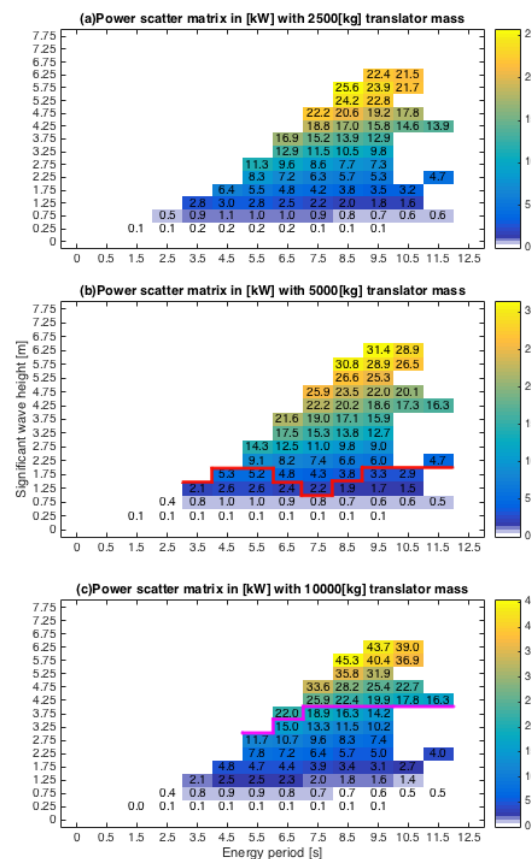


Figure 11. Average power (kW) matrix based on the wave climate at Site 6: (a) with a 2500 kg translator; (b) with a 5000 kg translator; (c) with a 10,000 kg translator. The red boundary line results from the comparison between (a) and (b); the violet boundary line results from the comparison between (b) and (c).

Annual energy production was further studied in order to yield a comprehensive comparison among the three cases of translator mass. The total energy production was calculated for each case and given in Table 4. Both of the red and violet boundaries have the same function as in Figure 11. Results showed that the linear generator with the 5000 kg translator achieved the most energy production among the three cases, while the 10,000 kg translator was at a disadvantage under the wave climate at Test Site 6. Results in Figure 12 with the boundary lines suggest the impact of different translator masses on the energy production for each wave climate. For instance, in Figure 12c, the heavier translator (10,000 kg) contributed to less energy production at the area of wave climates below the violet line. The reason for this was that more wave energy was consumed to drive the translator and more energy was lost through absorption.

Table 4. Annual energy production with three translator masses at Test Site 6.

Translator Mass (kg)	Annual Energy Production (MWh)
2500	21.62
5000	22.57
10,000	20.83

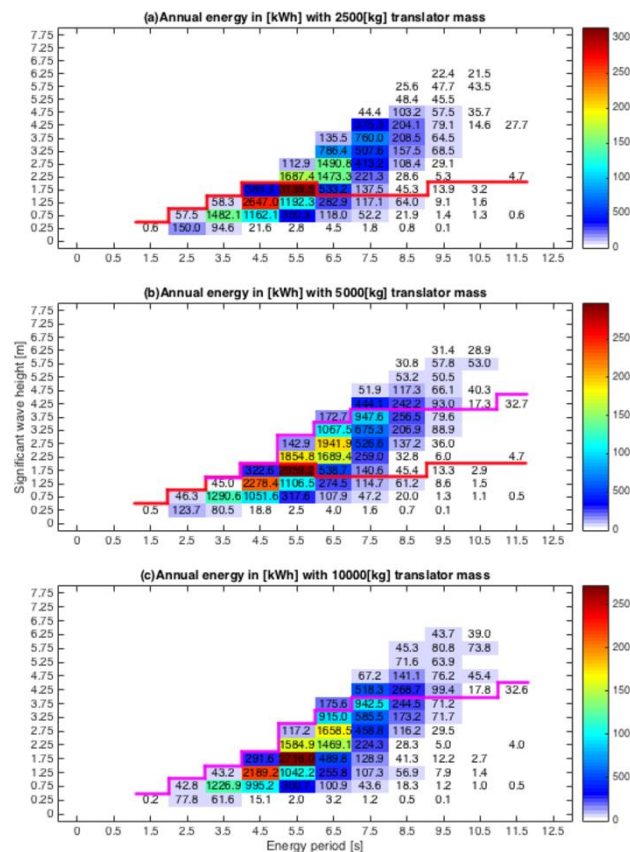


Figure 12. Annual energy (kWh) matrix based on the wave climate at Site 6: (a) with a 2500 kg translator; (b) with a 5000 kg translator; (c) with a 10,000 kg translator. The red boundary line results from the comparison between (a) and (b); the violet boundary line results from the comparison between (b) and (c).

4. Conclusions

The results firstly suggest the significant impact of translator mass on power generation. The results show that a heavier translator will lead to a higher amount of potential energy. The higher potential energy can be harnessed as the translator moves downwards during the latter half of the wave period. Problems can be caused when the damping coefficient is too high. The buoy moves down in wave troughs with a higher velocity than the translator. In such a case, the movement of the translator is restricted through the stator before the buoy pulls the translator upwards again. This will lead to low conversion efficiency of the generator, and therefore lower energy absorption. If the translator is too heavy, lower excitation force from weak sea states might be insufficient to drive the translator.

Secondly, the optimal damping coefficient was observed by shifting the translator mass. The value of the optimal coefficient tended to increase for the heavier translator; otherwise it decreased. The results indicate that translator mass is essential for optimal damping control topology when aiming to optimize energy production.

Lastly, the comparison of translator mass was further adopted to investigate the annual energy production at the studied site off the west coast of Sweden. The results and discussion led to the

conclusion that higher translator mass may contribute to higher energy production but may also have a hindering effect, depending on specific environmental conditions. Therefore, in order to enhance the extraction of wave energy, the wave climate at the research site should be taken into account when designing a proper translator mass for WEC. However, the research in this paper is focused on the damping effect coupled with translator mass rather than a combination with more mechanical factors. Therefore, a more comprehensive study with other factors should be included in future works, in order to fully research the optimal damping effect which is able to optimize WEC performance.

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