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Impact of technical power take-off constraints on the power extraction of unidirectional and bidirectional point absorbers

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Abstract

Purpose – The purpose of this paper is to quantify the impact of the constraints of the power take-off system (PTO) on the power extraction of a point absorber wave energy converter (WEC). Such constraints include power, torque and maximum stroke limitations. Two different concepts, unidirectional and bidirectional point absorbers, are analysed, which both are relevant for practical applications in the wave energy industry.
Design/methodology/approach – The two different cases of unidirectional and bidirectional point absorbers are analysed and directly compared. Moreover, a simplified control strategy is considered for the point absorber, which is based on a constant torque reference. The WEC performance is first evaluated in selected sea states and then the analysis is extended to assess the impact of the different solutions on the expected yearly wave energy production of the point absorber, when deployed at a specific location. The European Marine Energy Center (EMEC) is selected as the target site for the analysis.
Findings – The analysis was performed in selected sea states and then it was extended to all the sea conditions occurring at the EMEC test site. The comparison between unidirectional and bidirectional operated devices suggested a clear superiority of the latter, ensuring similar power extraction at the expense of a halved required torque by the PTO. Moreover, a selective control strategy was implemented, and the results showed an increase in yearly energy production for the bidirectional device.
Research limitations/implications – The study proved the importance of including the actual PTO constraints in the preliminary power assessment in order to avoid unrealistic overestimation of the expected power performance.
Originality/value – The paper quantifies the power performance obtained with the application of such control strategy considering both unidirectional and bidirectional point absorbers. This analysis and comparison is extremely relevant since both unidirectional and bidirectional devices are reaching the market.

Keywords Electric power generation, Hydrodynamics, Hydromechanics, Wave energy, Point absorber, Unidirectional, Bidirectional, Power take-off, Marine energy
Paper type Research paper

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1. Introduction

Wave energy is gaining momentum as a potential contributor to the world energy portfolio (OES, 2011), due to its large and distributed availability and high predictability. Many concepts for wave energy conversion are being tested worldwide which are based on very different principles of operation (López *et al.*, 2013). Among them, point absorbers (Budar and Falnes, 1975) are showing to be promising due to their limited infrastructural cost and easy scalability. One of the biggest challenges for such wave energy converters (WECs) is the control strategy, which needs to be optimized to maximize the power extraction from the waves. Many point absorber control techniques with different degrees of complexity have been investigated in the past decades. In the wave energy industry, however, the most straightforward solutions are generally preferred for practical applications, such as those derived directly by linear control techniques (Shek *et al.*, 2007; Stålberg *et al.*, 2008; Sjolte *et al.*, 2013). The first goal of this paper is to evaluate the performance of a simplified control strategy, which consists of applying a constant (in module) torque to the point absorber. Moreover, the paper quantifies the power performance obtained with the application of such control strategy considering both unidirectional and bidirectional point absorbers. This analysis and comparison is extremely relevant since both unidirectional (Sjolte *et al.*, 2013; Josefsson *et al.*, 2011) and bidirectional (Danielsson *et al.*, 2005) devices are reaching the market. Since real devices are seldom designed to capture peak power, an additional goal of this paper is to highlight the effects of under-sizing the power take-off system (PTO). This is done by first evaluating an unconstrained device, and comparing the results with different PTO constraints.

2. Model of the WEC

The system under analysis is schematically shown in Figure 1. It is composed of a point absorber, coupled with an all-electric PTO through a gearbox. The prime mover is a cylindrical buoy with a hemispherical bottom, which moves in heave only. Both the radius and the draught of the cylinder are equal to $r = d = 5$ m and the mass of the point absorber including the PTO is $M = 670140$ kg. The gear ratio of the gearbox is 20 and the pinion radius is 0.1 m. The size of the point absorber was chosen to be in line with real WEC prototypes (Babarit and Hals, 2011). Hydrodynamic coefficients have been calculated by using a commercially available software (ANSYS), although the hydrodynamic optimization of the point absorber is outside the scope of this paper.

The electric machine was chosen to be a permanent magnet synchronous generator. The machine is interfaced to the grid through a full converter. Additional details on the complete wave-to-wire system can be found in Alberti *et al.* (2012), Bozzetto (2013) and Bozzetto and Tedeschi (2014).

The WEC is simulated using one of two operating modes, i.e. unidirectional or bidirectional. In unidirectional mode the point absorber can only extract power in the

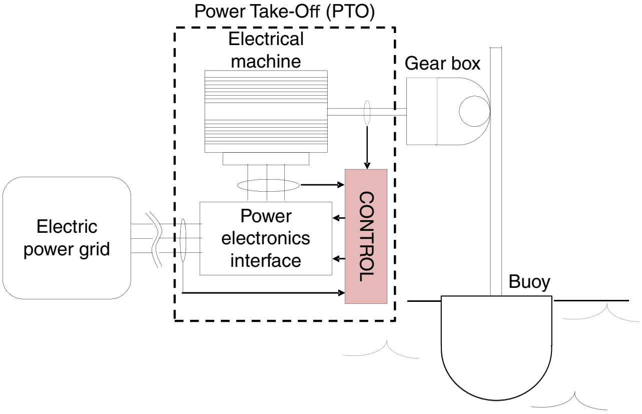


Figure 1.
Conceptual figure of the considered wave energy converter

upward heave motion of the buoy. During the downward motion there is no torque applied by the PTO. In bidirectional mode the PTO applies a torque in both heave directions of the floater. The two operation modes are illustrated in Figure 2. The figure shows an idealized operation with a regular wave. As can be observed, the velocity profile in Figure 2 is unaffected by the non-linear variation in the applied PTO force, and the bidirectional device would extract twice the amount of energy compared to the unidirectional device. This shows the idea and possible advantage of this concept, although the power outtake will decrease for a non-idealized case. The here presented analysis will be especially focused on the mechanical power extraction. The effect of the limited rating of the PTO which reflects the actual size of the electrical machine and power electronics converters will be specifically investigated. However, this does not require the detailed modelling of all the PTO components.

2.1 System modelling

In order to quantify the mechanical power extraction of the considered WEC, the interaction between the waves and the point absorber is modelled applying the linear water wave theory. The Cummins equation is therefore used (Cummins, 1962). The equation is shown:

$$(M+a_\infty)\ddot{x}_{buoy}(t)+\int_{-\infty}^{t}K_{rad}(t-\tau)\dot{x}_{buoy}(\tau)d\tau+\rho g S x_{buoy}(t)+F_{PTO}(x,\dot{x},\ddot{x},t)=F_E(t) \qquad (1)$$

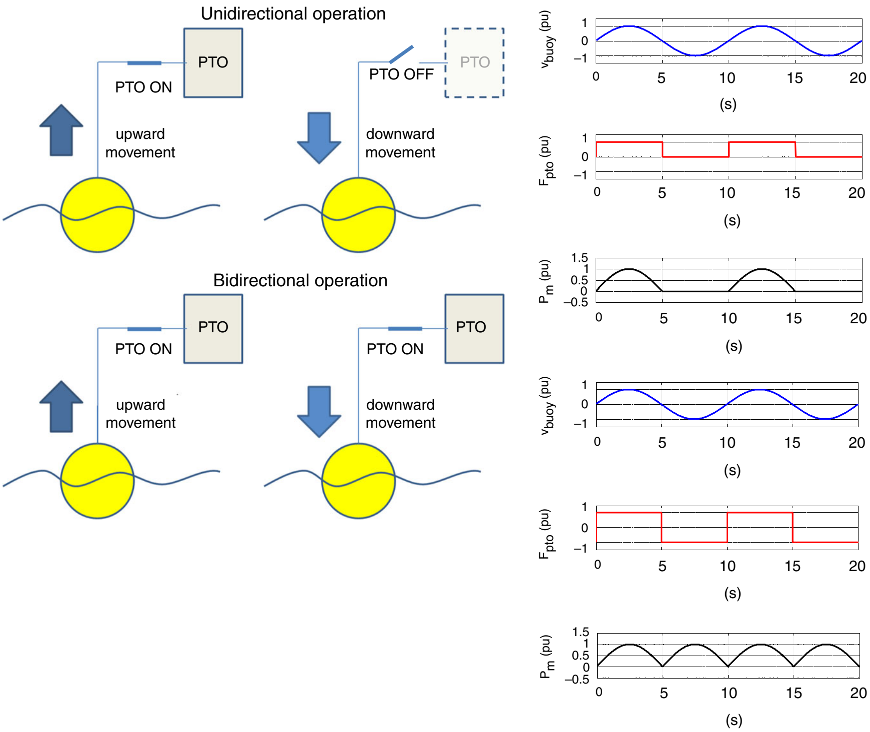


Figure 2. Principle of operation of unidirectional and bidirectional point absorbers and corresponding buoy velocity (v_{buoy}), PTO applied force, (F_{PTO}), and extracted mechanical power (P_m) under ideal sinusoidal wave conditions

In (1), M is the mass of the point absorber, including the mass of the PTO and a_∞ the corresponding added mass at infinite frequency; x_{buoy} the point absorber position and the dot sign indicates time derivative operation. The convolution product represents the radiated waves created by the buoy moving on the water. $K_{rad(t)}$ is the radiation impulse response function, representing a memory effect due to the radiation forces originated by the past motion of the floater. Furthermore, ρ the water density, g the gravity constant and S the area defined by the intersection between the free surface and the buoy. The force applied by the PTO to the buoy is indicated as F_{PTO} and F_E the excitation force exerted on the buoy by the waves. Hydrodynamic parameters such as damping and added mass have been obtained by using a boundary element code (ANSYS), while the convolution integral accounting for the radiation force has been modelled as a transfer function, which was derived by a frequency domain identification procedure, according to (Pérez and Fossen, 2008). A simulation model was built in Matlab/Simulink©, which corresponds to the block diagram shown in Figure 3. The mechanical power extraction of the WEC can be calculated as the product between the force applied by the PTO, F_{PTO}, and the buoy velocity:

$$p_m = F_{PTO} \cdot \dot{x}_{buoy} \tag{2}$$

3. Performance in reference sea states

The first step in evaluating the performance of the point absorber was to subject it to different reference sea states. Three different states where chosen with, respectively, low, medium and high-energy content.

The low-energy sea state had a significant wave height $H_s = 1.4$ m and zero crossing period $T_Z = 6.5$ s. The medium-energy sea state was set to $H_S = 3.75$ m and $T_Z = 8$ s. The last sea state was a high-energy sea state with $H_s = 5.75$ m and $T_Z = 10.5$ s. The Bretschneider spectrum (Michel, 1999) was used to model each sea state and a time domain expression for the wave elevation profile can be derived from the given spectrum. The corresponding excitation force F_E can be calculated once the geometry and properties of the floater are defined, as explained in Ansari and Khan (1989).

3.1 Power capture with unconstrained PTO

To establish a reference base case, the PTO was simulated without constraints, effectively having a PTO of unlimited size that allows for extraction of as much power as possible from each sea state. A PTO of unlimited size can be expected to have inertia of about an order magnitude larger than for the constrained case. Still, the added mass is negligible compared to the mass of the floater and thus not included in the following calculations. Such test should be considered as a best-case evaluation of the extractable

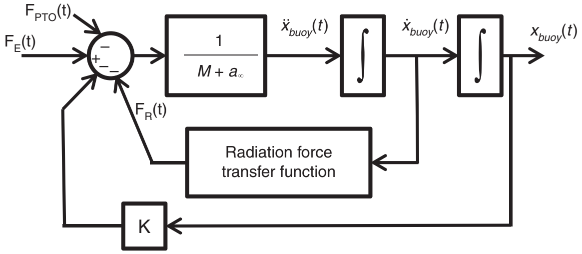


Figure 3.
Hydrodynamic model of the point absorber

power by the considered device in each sea state. The power extraction from the point absorber was evaluated using different values of constant torque applied by the PTO, which allows for evaluation of which torque value that results in the highest power capture in each sea state both for the unidirectional and the bidirectional cases. The torque value is a relevant parameter since it affects the electrical machine and converter design. The results are reported in Table I, where P_m is the average mechanical power in the considered sea state and T_{PTO} represents the applied PTO torque that maximizes such power. P_{max}/P_m is the peak-to-average power ratio. It is interesting to note that the maximum mechanical power extracted by the point absorber is the same in both the bidirectional and unidirectional case. The unidirectional point absorber, however, requires an applied torque that is about twice the one required by the bidirectional device. For this simplified case, this is a result of the fact that the available energy in the waves is the same for the same period and significant wave height. However, the specific conditions for each WEC to extract the maximum available energy are different. Here, the unidirectional device needs double the torque since it has half the duty cycle of the bidirectional device.

From the results with the unconstrained PTO it can be seen that extracting the maximum possible power from each sea state requires a highly over-sized PTO, as already noted in (Tedeschi and Molinas, 2012). The very high peak-to-average ratio indicates that it would be uneconomical to design the PTO according to the peak power occurrence. In such a case the capacity factor of the PTO would decrease which indicates the payback compared to the investment cost would be lowered. It is also observed that the bidirectional device approximately halves the torque and maximum to average power ratio.

3.2 Power capture with constrained PTO

To approach a real device, constraints are applied to the PTO (Tedeschi and Molinas, 2010a, b). In this paper a twofold limitation is considered to resemble a real system. The first one is related to the limited PTO rating, which is a limit to the maximum power that the PTO can output. The power limit is enforced by a flux weakening control system that works in the following way; when operating close to the power limit, the torque applied to the point absorber is decreased proportionally to the point absorber velocity so that the instantaneous power limit is never exceeded (Tedeschi *et al.*, 2010). Moreover, under this operating condition, the applied torque is kept constant only when the extracted power is lower than the power limit. Otherwise the torque is reduced to ensure that the power constraint is not violated. In all simulations with constraints, the PTO power limit was set to 100 kW. This value was optimized according to the point absorber performance in low and medium-energy sea states, which prevail in the target location which will be clarified in Section 4.

An additional constraint was imposed on the system, which was required in order to avoid excessive (higher than 5 m) oscillations of the point absorber. Such oscillation

Table I.
Point absorber performance with unconstrained PTO

	Unidirectional mode			Bidirectional mode		
	P_m (kW)	T_{PTO} (kN m)	P_{max}/P_m	P_m (kW)	T_{PTO} (kN m)	P_{max}/P_m
Low energy	17	0.9	16.95	17	0.45	8.47
Medium energy	125	4.2	13.28	125	2.2	7.17
High energy	290	7.4	14.92	290	3.6	8.26

would trigger the floater to go mostly out of the water or be completely submerged during part of the operation. Thus, the system is considered to be equipped with mechanical end stops, which apply an external force from +/−4.8 m displacement from the equilibrium point to limit the stroke of the buoy within the allowed range. This form of "position control" is implemented independently on the PTO and thus its intervention does not affect the PTO rating or performance. It is also worth noting that, unlike the power limit, the buoy position control intervenes sporadically and only in the high-energy sea state. The results of the system performance with a 100 kW PTO are reported in Table II.

The average extracted power in the medium and high-energy sea states is significantly reduced. Compared to the unconstrained case, the power extraction of the unidirectional device is reduced to 32 and 14 per cent while the bidirectional device is reduced to 54 and 27 per cent. However, the peak-to-average power ratio is much more favourable which signifies the impact of the power limit. In the case a PTO power limitation is applied, although the reference torque is increased, the actual operation of the system will anyway force a torque reduction whenever the speed overpasses the rated value, i.e. most often during high-energy sea states. As a consequence of that, increasing the torque reference is not advisable, since the higher PTO sizing, i.e. installing a high torque machine, will not correspond to an actual increase in the average power extraction. Furthermore, it is not convenient to design the system to optimize the power capture in high waves if the selected WEC location has a higher occurrence of medium and low-energy sea states. Most often, the design optimization should be focused on medium-energy sea states that are the main contributors to the yearly energy extraction. The potential reduction of the PTO torque to be applied in the high-energy sea states will be further addressed in the next paragraph, to quantify its impact on the yearly operation of the point absorber at a specific location.

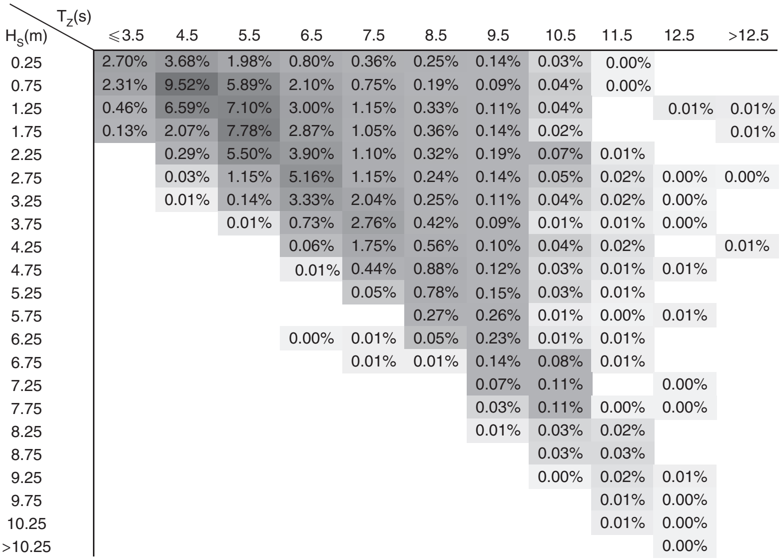
Overall, the previous analysis shows that the bidirectional point absorber is highly favourable due to the lower applied torque compared to the unidirectional device while ensuring the same power extraction. It also proves the importance of including the main constraints present in real systems for a fair assessment of the expected power performance of a WEC. As previously shown, an analysis that neglects this aspect would largely overestimate the power capture of the device. In addition, the lack of constraints would lead to inaccurate conclusions when comparing the two different operating modes of the point absorber.

4. Yearly energy extraction at a target site

The following analysis quantifies the expected yearly energy extraction of the considered WEC when deployed at a specific location. The selected location is the European Marine Energy Center (EMEC) site, located in the Orkney Islands. The EMEC wave climate can be evaluated based on the data of the yearly occurrence of each sea state, which are shown in Figure 4 (Nielsen and Pontes, 2010).

Table II. Point absorber performance with constrained PTO with a power limit of 100 kW

	Unidirectional mode			Bidirectional mode		
	P_m (kW)	T_{PTO} (kN m)	P_{max}/P_m	P_m (kW)	T_{PTO} (kN m)	P_{max}/P_m
Low energy	15.65	0.9	6.40	16.41	0.45	6. 10
Medium energy	40.54	1.5	2.47	67.91	1.0	1.47
High energy	40.85	3.8	2.45	78.80	1.9	1.27

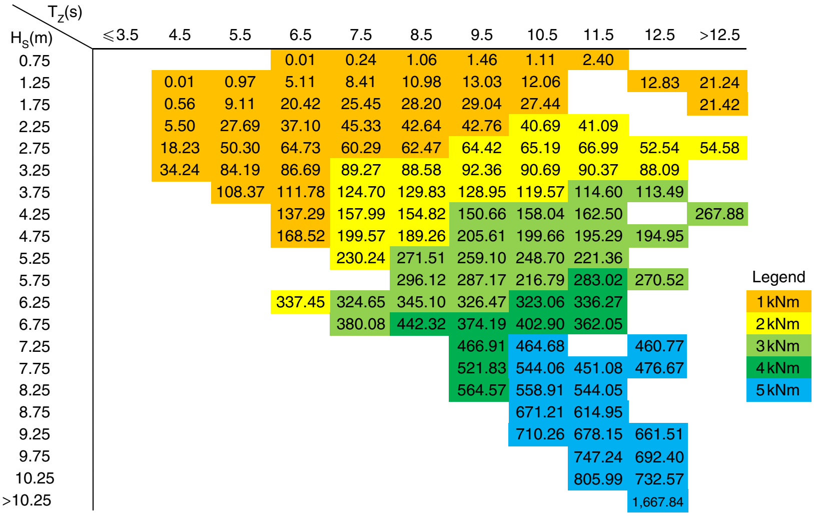


H_S(m) \ T_Z(s)	⩽3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	>12.5
0.25	2.70%	3.68%	1.98%	0.80%	0.36%	0.25%	0.14%	0.03%	0.00%		
0.75	2.31%	9.52%	5.89%	2.10%	0.75%	0.19%	0.09%	0.04%	0.00%		
1.25	0.46%	6.59%	7.10%	3.00%	1.15%	0.33%	0.11%	0.04%		0.01%	0.01%
1.75	0.13%	2.07%	7.78%	2.87%	1.05%	0.36%	0.14%	0.02%			0.01%
2.25		0.29%	5.50%	3.90%	1.10%	0.32%	0.19%	0.07%	0.01%		
2.75		0.03%	1.15%	5.16%	1.15%	0.24%	0.14%	0.05%	0.02%	0.00%	0.00%
3.25		0.01%	0.14%	3.33%	2.04%	0.25%	0.11%	0.04%	0.02%	0.00%	
3.75			0.01%	0.73%	2.76%	0.42%	0.09%	0.01%	0.01%	0.00%	
4.25				0.06%	1.75%	0.56%	0.10%	0.04%	0.02%		0.01%
4.75				0.01%	0.44%	0.88%	0.12%	0.03%	0.01%	0.01%	
5.25					0.05%	0.78%	0.15%	0.03%	0.01%		
5.75						0.27%	0.26%	0.01%	0.00%	0.01%	
6.25				0.00%	0.01%	0.05%	0.23%	0.01%	0.01%		
6.75					0.01%	0.01%	0.14%	0.08%	0.01%		
7.25							0.07%	0.11%		0.00%	
7.75							0.03%	0.11%	0.00%	0.00%	
8.25							0.01%	0.03%	0.02%		
8.75								0.03%	0.03%		
9.25								0.00%	0.02%	0.01%	
9.75									0.01%	0.00%	
10.25									0.01%	0.00%	
>10.25										0.00%	

Figure 4.
Wave distribution at the EMEC site for a whole year

First, the point absorber with an unconstrained PTO applying the above explained control strategy was deployed at the EMEC site. Several different reference torque values were tested to determine which of them ensures the highest energy extraction over a year. In each test the torque reference value is kept constant in all the different sea states. Both the unidirectional and the bidirectional devices were evaluated. The torque reference which gave the highest power production for each sea state was noted. An example of these identified torque references and the resulting average power is shown for an unconstrained bidirectional device in Figure 5.

These optimal operating points were used to form a selective control strategy. This strategy optimizes the maximum torque reference according to the current sea state.



H_S(m) \ T_Z(s)	⩽3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	>12.5
0.75				0.01	0.24	1.06	1.46	1.11	2.40		
1.25		0.01	0.97	5.11	8.41	10.98	13.03	12.06		12.83	21.24
1.75		0.56	9.11	20.42	25.45	28.20	29.04	27.44			21.42
2.25		5.50	27.69	37.10	45.33	42.64	42.76	40.69	41.09		
2.75		18.23	50.30	64.73	60.29	62.47	64.42	65.19	66.99	52.54	54.58
3.25		34.24	84.19	86.69	89.27	88.58	92.36	90.69	90.37	88.09	
3.75			108.37	111.78	124.70	129.83	128.95	119.57	114.60	113.49	
4.25				137.29	157.99	154.82	150.66	158.04	162.50		267.88
4.75				168.52	199.57	189.26	205.61	199.66	195.29	194.95	
5.25					230.24	271.51	259.10	248.70	221.36		
5.75						296.12	287.17	216.79	283.02	270.52	
6.25				337.45	324.65	345.10	326.47	323.06	336.27		
6.75					380.08	442.32	374.19	402.90	362.05		
7.25							466.91	464.68		460.77	
7.75							521.83	544.06	451.08	476.67	
8.25							564.57	558.91	544.05		
8.75								671.21	614.95		
9.25								710.26	678.15	661.51	
9.75									747.24	692.40	
10.25									805.99	732.57	
>10.25										1,667.84	

Legend
1 kNm
2 kNm
3 kNm
4 kNm
5 kNm

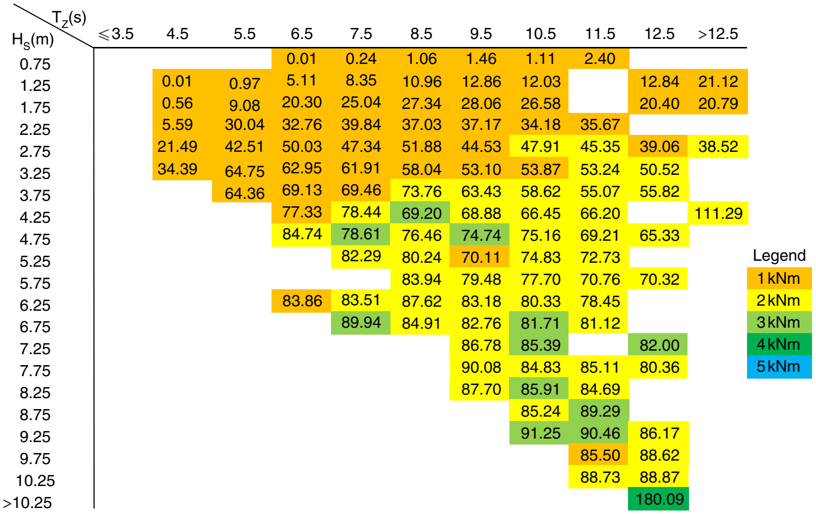
Figure 5.
Maximum torque reference according to sea state for an unconstrained bidirectional device which results in the highest average power. This information is then used to form a selective control strategy

Such a strategy concept is comparable to maximum power point tracking in solar power. For each sea state, the optimal maximum torque reference is found from the table information. As can be observed from Figure 5, in the considered case it is advisable to increase the torque reference with increasing wave height and period, although a further increase beyond 5 kN m will lead to a power extraction decrease due to the extensive reduction of buoy velocity. Further, to identify the difference in designing PTOs with higher torque capability, the selective control strategy was also tested with torque constraints. The strategy would be limited to select references in the range of 1-5 kN m, e.g, a 3 kN m limitation translates to the strategy choosing from 1, 2 or 3 kN m reference to maximize power output. The yearly energy production was registered for different limitations and operating method. The results are shown in Table III.

The same procedure was applied to a constrained PTO case, identifying the optimal maximum torque references for the different sea states at the EMEC site. The results are seen in Figure 6. Compared to the unconstrained case, it is clear that the optimal torque reference decreases for a constrained PTO. This characteristic is favourable for the real case implementation. From the data in Figures 5 and 6 it can be noticed that the control strategy limiting the maximum power in the system slightly affects the average power extraction also in those sea states where the same optimal torque is applied in

Max torque reference	1 kN m	2 kN m	3 kN m	4 kN m	5 kN m
	Unconstrained PTO				
Unidirectional	226.8 MW h	290.0 MW h	321.0 MW h	336.1 MW h	345.4 MW h
Bidirectional	259.2 MW h	303.3 MW h	317.0 MW h	320.6 MW h	321.9 MW h
	PTO with power limit of 100 kW and buoy position control				
Unidirectional	150.0 MW h	154.2 MW h	154.7 MW h	154.9 MW h	154.9 MW h
Bidirectional	184.3 MW h	185.9 MW h	186.0 MW h	186.1 MW h	186.1 MW h

Table III. Yearly power production by selective control, adapting the maximum torque signal according to sea state



T_Z(s) / H_S(m)	⩽3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	>12.5
0.75				0.01	0.24	1.06	1.46	1.11	2.40		
1.25		0.01	0.97	5.11	8.35	10.96	12.86	12.03		12.84	21.12
1.75		0.56	9.08	20.30	25.04	27.34	28.06	26.58		20.40	20.79
2.25		5.59	30.04	32.76	39.84	37.03	37.17	34.18	35.67		
2.75		21.49	42.51	50.03	47.34	51.88	44.53	47.91	45.35	39.06	38.52
3.25		34.39	64.75	62.95	61.91	58.04	53.10	53.87	53.24	50.52	
3.75			64.36	69.13	69.46	73.76	63.43	58.62	55.07	55.82	
4.25				77.33	78.44	69.20	68.88	66.45	66.20		111.29
4.75				84.74	78.61	76.46	74.74	75.16	69.21	65.33	
5.25					82.29	80.24	70.11	74.83	72.73		
5.75						83.94	79.48	77.70	70.76	70.32	
6.25				83.86	83.51	87.62	83.18	80.33	78.45		
6.75					89.94	84.91	82.76	81.71	81.12		
7.25							86.78	85.39		82.00	
7.75							90.08	84.83	85.11	80.36	
8.25							87.70	85.91	84.69		
8.75								85.24	89.29		
9.25								91.25	90.46	86.17	
9.75									85.50	88.62	
10.25									88.73	88.87	
>10.25										180.09	

Legend
- 1 kNm
- 2 kNm
- 3 kNm
- 4 kNm
- 5 kNm

Figure 6. Maximum torque reference according to sea state for a bidirectional device limited to 100 kW power output which results in the highest average power. This information is then used to form a selective control strategy

both cases. This is due to the non-linear effect introduced by the power limitation, which modifies both the applied torque and the velocity profile of the point absorber.

Again the optimal maximum torque reference information was used to apply a selective control strategy with limits within the range 1-5 kN m. The results are seen in Table III.

In the unconstrained case, an increase in yearly energy production is observed with increasing allowable maximal torque. This is as expected, since more energy can be extracted in higher sea states. An increase from 1 to 5 kN m maximum torque leads to an increase of 52 per cent for unidirectional and 24 per cent for bidirectional. However, as already pointed out unconstrained PTO design is highly unlikely, and is should be regarded as a best-case scenario.

For the constrained case there is only a slight increase in yearly energy production with increasing maximum torque of 3 per cent for unidirectional and 1 per cent for bidirectional. Since the increase in yearly energy production is so low, the further analysis will focus on the 1 kN m reference torque.

As expected, the introduction of the electro-mechanic constraints causes an overall reduction of the yearly extracted energy compared to the unconstrained case. For the 1 kN m max torque reference the yearly production decreases to 66 and 71 per cent for the unidirectional and bidirectional devices, respectively, when constraints are introduced. Comparing the bidirectional device to the unidirectional device, not only is the decrease in production lower, but the absolute production also increases compared to the unidirectional device with 23 per cent. These aspects further promote the bidirectional device. At the same time this confirms once more the importance of including the actual PTO constraints in preliminary analysis, to avoid the risk of an overestimation of the total energy assessment.

Moreover, another observation is made about the design and operation of the point absorber with constraints. After the machine has been designed for a maximum torque level, the control system should still be tuned to run at lower torque references for maximum energy extraction. Using the numbers from these results, a 2 kN m unidirectional constrained PTO could obtain a 18 per cent increase in yearly energy production by running at both 1 and 2 kN m references (1 kN m constant torque reference leads to a 150.0 MW h yearly production and a 2 kN m constant torque reference leads to a 154.2 MW h yearly production). This would be valid for a case where the machine size is already decided. If instead the machine parameters are still to be decided then these results can be used to evaluate the optimal sizing. For example, in the case of a unidirectional device, then a machine with a 2 kN m maximum torque over 1 kN m maximum torque would result in an approximately 1 per cent increase in yearly energy production, for which the value stream can be compared to the increased investment cost.

5. Conclusion

This paper studied the power performance of a point absorber with an all-electric PTO, when a control technique using a constant torque reference is applied. The investigation carried out at first considering and ideal (unconstrained) PTO, and then including the constraints due to the limited PTO rating and buoy maximum stroke. First, the analysis was performed in selected sea states and then it was extended to all the sea conditions occurring at the EMEC test site. A comparison was shown between unidirectional and bidirectional operated devices, which suggested a clear superiority of the latter, ensuring similar power extraction at the expense of a halved required torque by the PTO. Moreover, a selective control strategy was implemented, and the results showed an increase in yearly energy production. Finally, the study proved the importance of including the actual PTO constraints in the preliminary power assessment in order to avoid unrealistic overestimation of the expected power performance.

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Further reading

Ocean Power Technology, available at: www.oceanpowertechnologies.com

ANSYS. ANSYS Aqwa software, available at: www.ansys.com/Products/Other+Products/ANSYS+AQWA

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