Airborne and underwater noise assessment at the Pico OWC Wave Power Plant

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Abstract

The recent push for the implementation of full scale Wave Energy Converters has resulted in the successful deployment of some technologies. As a result of a 3 year recuperation and renovation project the OWC in the Pico Island, Azores has recently began to operate on a frequent basis. Consequently, and particularly due to the plausible proximity of this type of technology to populations, the need to assess the noise impacts of this technology has arisen. Furthermore the Azores is inhabited by an important population of marine mammals, particularly cetaceans, and therefore the underwater noise produced must also be addressed. The present paper describes the methodologies currently being tested at the plant, both for airborne and underwater noise, as well as some preliminary results. Factors needed to be considered for noise assessment at OWC plants, potential uses of noise in this technology and future noise studies are also discussed.

Keywords: Noise Impact Assessment, Pico Plant, OWC, Wave Energy

1. Introduction

Noise can be defined as unwanted sound. This definition implies that it can have adverse effects not only on human beings but also on the environment by interfering with natural wildlife. Over the past decades anthropogenic sources of sound have increased considerably [1], particularly from industrial activities, and this has led to a growing awareness and concern on its potential impact. This is true both for airborne noise, where impacts on human populations are taken into account, and for underwater noise where fauna and particularly marine mammals are a priority concern. Although the specific impact of noise can, in specific cases, be hard to prove categorically the disturbance on humans and wildlife has been an important research focus [3-4-5]. Therefore it is important to create methodologies to assess and monitor the noise generated by new activities that are introduced into the marine environment. For all of these reasons noise is an important descriptor of an Environmental Impact Assessment (EIA).

In principle less noise can be expected from wave energy projects than from other existing maritime activities [2] (e.g. pile driving, air gun pulses, shipping) however the noise emitted will vary from technology to technology and be highly dependent on the number of devices deployed and layout. Presently the majority of prototypes and projects for wave energy devices are designed to operate offshore (50-70m depth) as this is where the wave resource is more abundant. Nonetheless, partially due to financial and logistic issues associated with going offshore, the on-shore Oscillating Water Column (OWC) technology has undergone many years of research and development consistently and may become an established technology in the near future.

The OWC technology consists of harnessing the energy from waves by using the rising and falling water surface in an air compression chamber to create a bi-directional air flow. This flow is then used to drive a turbine which must rotate continuously in the same direction regardless of the air flow in order to avoid a complex and expensive valve system. The Wells turbine has been tested in several pilot projects and alongside the Impulse turbine is considered to be the most viable way of extracting energy from an OWC plant.

In Portugal there is an operational OWC pilot plant at the Pico Island, which was used as a case study for this paper. The plant was concluded in 1999, however after some major technical and financing issues the project was halted for several years. Since 2003, under co-ordination of the Wave Energy Centre (WavEC), the plant has been undergoing a recovery and testing program aiming to address the technical limitations of the plant and to rehabilitate it in order to serve as a research facility and a berth for turbine testing [5].

Since 2008 the plant has ran several operational tests and the improvements have enabled it to steadily increase its operation times having completed 265 hours in 2009 and 450 by May in 2010. In addition there is currently an effort to automate the plant so that it can be operated remotely and consequently much longer operational periods are expected in the near future. This has enabled and incentivized the development of studies focused on the noise produced by the plant. It should be taken into account that due to its history and particular tentative set-up, the plant can be considered an example of a “worst-case-scenario” regarding noise issues. The objective of the present study was to develop preliminary procedures to characterize and assess the noise emitted by this OWC plant, both airborne and underwater, and to present preliminary results to a wider community.

2. Airborne noise

2.1 Introduction

The OWC technology raises very prominent issues regarding noise, this is because, unlike offshore devices, in addition to the underwater noise generated it may produce airborne noise that can affect human populations and land fauna. Besides it is expected that this technology can be deployed in close proximity to inhabited areas, either as stand alone projects or incorporated into breakwaters. Furthermore the noise produced will be highly variable as it is dependent on several factors which are can be hard to combine and evaluate independently. These include for example the wave climate (wave height, period and direction), morphology of the surrounding terrain, atmospheric conditions (wind direction, wind intensity, humidity) and operational conditions (wave interactions in the chamber, rotational speed, relief valve position, control law). For the scope of this study the atmospheric and wave conditions will not be addressed specifically as they were very similar throughout the campaign (significant wave height of 1.5 to 2.5m and N wind of 6 to 9 m/s) and the focus will be on a preliminary characterization of the plant.

2.2 Methods

For the Airborne noise measurements a Larson Davis, LxT1 Class 1 soundmeter was used. It was set up on a tripod at 1m and configured to measure all parameters in a continuous rise over a period of 30 minutes for each measurement point. This period of time was selected to take into account the inherent variation imposed by the wave regime and the associated importance of recording the larger wave *sets*. All measurements were performed in 1/3 octave. Low frequencies i.e. from 6,3 to 20 Hz were also considered and measured. The Leq was weighted in A and L (Linear). The location of the measurement points were allocated to assess several of the influences that the noise of the plant might have, therefore points were located in the direct line of site of the turbine (10, 4), direct line of site of the relief valve (7, 8) within the closest populations (2, 3, 5) and also in increasing distance from the plant (6, 11, 12). The points can be seen in **Figure 1** and their distance from the plant in **Table 1.** Different operational conditions were also considered, these are described in **Table 2**.

Figure 1: Location of the measurement points

Point	Distance to the Plant (m)
1	55m
2	107m
3	178m
4	260m
5	155m
6	260m
7	70m
8	150m
9	170m
10	75m
11	400m
12	1000m

Table 1: Distance from the measuring points to the plant

Measurement Settings	Plant On – Valve 0% Open
	Plant On - Valve 25% Open
	Plant On - Valve 100% Open
	Plant Off – Valve 100% Open

Table 2: Operational conditions considered

2.3 Results and analysis

The **Figure 2** below illustrates the oscillations in LAeq and frequencies over time. The double peaks represent the differences in noise produced when the air is traveling through the turbine in opposite directions. The first, and higher peaks, describe the noise produced as the air is expelled from the turbine and the second the air intake as the wave sucks air in. This particular time series also depicts a wave *set* that is clearly visible in the higher peaks of the graph. It should also be noted that the turbine frequently stalls when the air flow rises sharply, producing large amounts of noise, which may help account for the observed peaks.

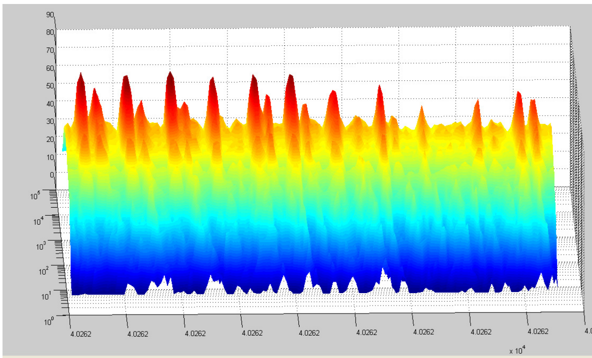

Figure 2: Time's History, LAeq vs Time vs Frequency in logarithmic scale.

The difference in sound level for each of the stations with the plant on and off are shownin the **Figure 3** below. Although it is evident that there is an increase while in operation the difference is not very high. This is partly due to the effect of the releave valve, that is fully opened while not in operation, and contributes with high frequency sound that can be out of the human hearing range.

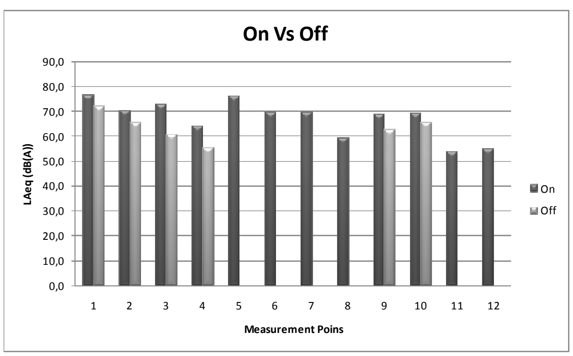

Figure 3: Comparison of noise level with plant on vs off

The average frequency distributions of the plant in operation are shown in the **Figure 4**. The largest proportion of noise emitted from the plant is within the human hearing range within 1000 and 2500 Hz. It should also be noted that there a peak can be found at 160 Hz which is probably a consequence of the rotational frequency of the turbine, however further research into the properties of the turbine and its frequency at the time of measurement would be required to confirm this.

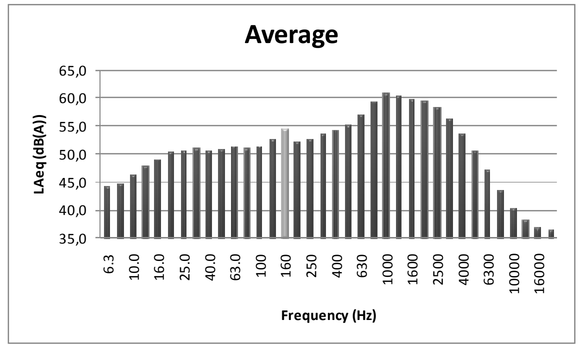

Figure 4: Average frequency distribution of all measuring points with relief valve at 25%

With the noise data collected at the different positions described in **Figure 1** it was possible to produce a noise map using MatLab software and Google Earth. **Figure 5** illustrates the sound map produced for an operating plant with a release valve open at 25%. The turbine duct is facing South and, as can be seen in the figure, is responsible for the greatest proportion of sound production. This clearly indicates that, particularly in the case of multiple OWC device integration in breakwaters, the turbine orientation will be a major factor to determine the noise impact expected.

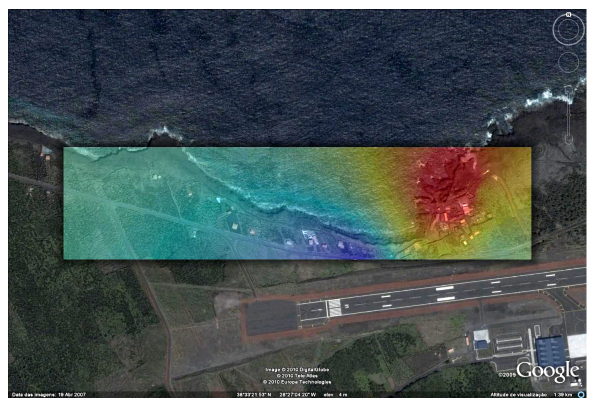

Figure 5: Sound map of an operating plant with a 25% open relief valve

3. Underwater Noise

3.1 Introduction

It is expected that each wave energy technology will have its own acoustic characteristics, i.e. the acoustic signature of the device. The OWC is a shoreline device which will have acoustic characteristics associated with the mechanical and specific components of this kind of technology, such as the turbine-generator group, the Wells turbine, and will also be influenced by the connection/interaction of the device with the water, through its walls in general and through the air chamber, where there are pressure differences.

The noise propagation paths are also related with the kind of device and with the environment where the device is deployed. In this case the noise will be propagated through the structure itself that is connected with the water (structure-water) and deployment site (rocky bottom-water), and air-water inside the air chamber and also outside, transmission of airborne noise to the water.

The significance of the study of the underwater noise generated by the Pico OWC, as mentioned before, is to allow the potential study of the effects of the noise on marine fauna, especially on marine mammals. In this specific case this WED is deployed on the Pico Island, one of the islands of the central group of the Azores Archipelago, where there is a particularly high abundance and diversity of marine mammals throughout the year. Since the last quarter of the 20th century a substantial level of cetacean ecological studies has been conducted in the Azores and to date twenty-eight cetacean species have been documented in the Azorean waters [6].

3.2 Methods

At this stage all the underwater noise campaigns performed at Pico plant are conducted through the WEAM Project (Wave Energy Acoustic Monitoring). Two separate data acquisition campaigns have been planned taking into account different purposes; the methodologies are described below **Table 3**. The recordings of the noise generated should aim to obtain relevant impact characteristics, such as, for example, maximum and average broadband sound pressure level (SPL), the amplitude spectrum in the frequency domain over different phases of operation, and duty cycle of noise production. These factors will help to assess the magnitude of the impact expected and which species are likely to be more vulnerable.

Campaign	**Fixed Position Recordings**
Objective	Acoustic characterization of the device
Deployment	As close as possible to the OWC. 10m in front of the chamber
Equipment	Autonomous hydrophone fixed on a tripod (**Figure 6**) structure on the rocky bottom.
Methodology	Recordings at a scheduled time in order to include daytime and nighttime sea states and different operational regimes of the OWC. (diver required)
Campaign	**On Vessel Recordings**
Objective	Assess noise propagation through the distance
Deployment	Transects in 3 different directions away from the OWC.
Equipment	Autonomous hydrophone (on a vessel)
Methodology	Recordings away from the OWC performed at predefined locations and water depth using an underwater noise recorder operated from a small vessel.

Table 3: Methodologies planned to data acquisition of underwater noise from OWC Pico Plant.

However, the implementation of these campaigns is complex and implies a compromise between the operational regimes, sea conditions and the purpose of each campaign needs to be achieved. On one hand it is necessary to have waves exceeding 1,2 -1,5m of significant wave height to operate the plant but on another hand a very calm sea state (> 1,5m) to allow divers to safely attach the autonomous hydrophone to the tripod. Waves of less than 2m are also required to perform recordings from the boat (6-7 hour each day of recordings).

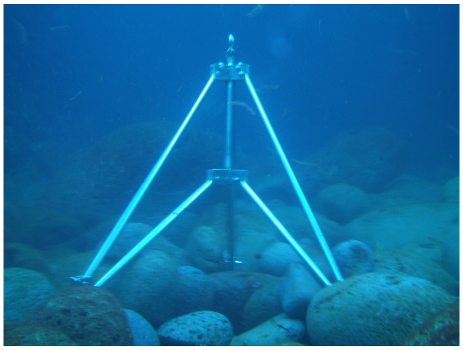

Figure 6: Tripod structure 10m in front of the OWC Pico Plant.

3.3 Results and analysis

To date only the fixed position recording campaign was carried out in May of 2010, but, due to sea conditions, only in early June was it possible to remove the hydrophone from the tripod. Consequently it was not possible to perform a data analysis in time for this paper.

4. Discussion

Regarding the airborne noise it was clear that the methodology adopted was appropriate and provided a large amount of data that can reveal a great deal of information on the noise emitted by the Pico Plant. Some relevant findings from the preliminary investigation done were the high influence of the larger wave *sets* on the instant noise produced; the expected lower noise levels when the plant is not operating although not by a large margin due to the influence of the open release valve while the plant is not operating.

It was also found that the large majority of the noise emitted during operation is found within the human hearing threshold between 1000 and 2500 Hz and therefore future projects should address impacts on neighboring populations. It was also noted that there was a particular frequency peak at 160 Hz which was probably due to the rotational frequency of the turbine. The noise map produced also highlighted that the influence zone of the plant under operation is considerable.

The underwater work is still an ongoing project and unfortunately, due to logistic issues with the retrieval of the hydrophone, there were no data to process. However the method employed for the fixed positions recordings was successful in retrieving data although it also highlighted the significant gap in logistic and practical complexity of making measurements at sea.

The present study gives a broad overview of the noise characteristics of the PICO OWC plant and can be seen as a first step into noise studies at the plant. The data retrieved to date can be used to assess a number of factors regarding the operation of the plant and besides addressing the various environmental and operational factors already mentioned there are also plans to use the noise to identify the stall events of the turbine. At present stalling occurs quite frequently when the air flow increases suddenly, such as when a large wave *set* reaches the plant. The stall not only raises the load on the whole turbine but it also creates drag within the turbine and breaks the rotational speed. At the moment there are no instruments to identify these events and noise levels, coupled with the acoustic signature of the stall could help characterize and prevent the occurrence of stall.

The data acquired will also be used to carry out an assessment of noise disturbance on the neighboring populations and eventually contribute to noise reduction measures that could be applied to the Pico and future OWC conversion plants.

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