Recent work and prospective analysis on offshore structures and marine energy harvesting at the Faculty of Engineering of the University of Porto

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Abstract. Marine energy harvesting and offshore structures for marine renewable energy exploitation rise as a trending topic of both research and industrial activities. However, many challenges are yet to be tackled and solved when it comes to place such equipment and structures at sea. Over the past years the Marine Energy Group at FEUP has been tackling some of those challenges aiming at a better competitiveness of marine renewable energy in comparison to traditional oil & gas sector, which is more mature and developed at this point in time. Additionally, recent findings of this research team have also been applicable to several offshore oil & gas infrastructures. In this work, the latest contributions, projects and research outcomes developed by the team are reviewed and presented towards the enhancement of future research lines and industrial opportunities.

1. Introduction

As the urgency to adapt to Climate Change becomes more and more evident, the modern World strives to look for new ways to explore the untapped potential of sea resources in both an efficient and sustainable manner. However, this is a mission full of challenges, knowledge gaps and opportunities to be tackled while the scientific and professional community dives deeper and deeper into the unknown wonders of remote locations at offshore sea.

From the traditional structures and foundations for offshore oil and gas to the marine renewable energy harvesting technologies, the desire to place resilient structures in offshore environment dates from more than 100 years ago [1]. In recognition of these facts, the Marine Energy Group, from the Faculty of Engineering of University of Porto (FEUP) and the Interdisciplinary Centre of Marine and Environmental Research (CIIMAR), has considered offshore structures as one of its key research lines over the twelve past years. The following describe the latest developments and research outcomes of the group.

2. Wave energy harvesting and applications

Within this field, an appealing topic of research is the development, optimisation and validation of novel concepts for wave energy harvesting. The group is involved on several national and international projects in this field, focussed on the assessment and optimization of wave energy converters (WECs) and hybrid technologies for marine energy harvesting, the stability of the supporting foundation, or on
the application of novel materials to improve the efficiency of innovative harvesting technologies, among other important topics.

A good example is the i.nano.WEC project that has been setting the pace on the application of triboelectric nanogenerators to efficiently harvest low amplitude and low frequency wave energy (Figure 1). This project represents a remarkable disruptive contribution to the effort to increase the use of highly efficient energy harvesting systems.

![Image](image1.png)

**Figure 1** – Left: Navigational buoy tested in FEUP’s wave basin under realistic wave conditions. Inset of the navigational buoy re-dimensioned in a 1:8 scale. Right (top): simplified scheme of the model's degrees of freedom. Right (bottom): TENG systems tested in the experimental study (from [2]).

The i.nano.WEC project demonstrated the possibility and high potential to sustainably power supply offshore equipment and infrastructures, such as those used for the continuous monitoring of environmental and human activities in remote oceanic locations, using the ocean wave energy, enabling also the long-term deployment of energetically autonomous systems for aquaculture, signalling or met-ocean markets [2], [3]. The use of novel and low-cost materials as the ones applied in i.nano.WEC may in the future provide synergies with prospective developments in other fields of activity. One of those being the use of offshore floating structures to produce sustainable energy as well.

Offshore floating platforms have an extent of motion that by far exceeds the displacements associated with sea bottom-fixed structures, such as jackets or monopiles. The E-Motions project addresses this aspect by focusing on the development of WECs for multipurpose offshore floating platforms, e.g. for oil and gas platforms or vessels [4]. The E-Motions technology was developed to be placed at the offshore platform itself, where the Power-take-off (PTO) system generates energy through the motion of a mobile mass attached to a generator. The mass motion results from the wave-induced roll oscillations of the structure. The E-Motions converter also provides added value by being simple and easy to implement in different offshore structures or devices (Figure 2).
3. Offshore foundations for multiple technologies

Another prospective field of research is the study of the behaviour and efficiency of novel marine energy harvesting technologies, for different types of foundation. As an example, the CECO WEC has been one of the concepts developed using physical and numerical modelling at FEUP, for varying configurations of the foundation. While in the preliminary studies, the PTO system was mounted in a monopile fixed at the seabed, the need to harvest energy in deeper water led to the development of different mooring systems to improve the concept's feasibility and efficiency (Figure 3).

![Figure 3](image_url)

**Figure 3** – Left: floating versions of CECO wave energy converter. Right: details on CECO's sloped PTO system.

Either focused on novel advanced materials, more efficient PTO systems or the optimised integration with offshore foundations, interesting perspectives arise from the recent research conducted by the group. The available experimental facilities at FEUP have a key role in this research and have already being used for proof of concept and demonstration of several well-known technologies for the harvesting of wave energy (Figure 4).
Figure 4 – Examples of wave energy converters tested in FEUPS’ wave basin: (a) WaveCat – Universidad de Santiago de Compostela, Spain, (b) Spar buoy concept with internal oscillating water column system – Technical University of Lisbon (Courtesy of Prof. Luís Gato – IST), (c) CorPower – CorPower Ocean, and (d) WaveRoller – AW Energy Oy (Courtesy of AW Energy oy).

4. Combining marine renewable energy with maritime and coastal structures

A noteworthy solution for wave energy harvesting that ensures a facilitated connection to the main power grid is deploying shore-based WECs integrated into the sheltering structures of seaports, i.e., in the breakwaters. Not only breakwaters are favoured structures to install WECs because of their high exposure to energetic wave conditions, but the port infrastructures also could greatly benefit from increasing the renewable energy portion in their energy mix, reducing their environmental impact by generating electricity on-site from a renewable source, as well as contributing to improving their sustainability and social perception. Innovative hybrid solutions combining different wave energy conversion principles have been developed in recent years [5] (Figure 5). This research line was initiated in the SE@PORTS project and is presently being developed within the PORTOS and WEC4Ports projects.
The optimisation of the harvesting technology and their cost-effective integration on existing types of offshore foundations represents a key opportunity to reach competitive costs for alternative marine renewable energy sources. These are still considerably more expensive than the sources used for commercial purposes nowadays, including the offshore wind energy. As an example, the wave energy Levelized Cost of Energy (LCoE) currently ranges roughly from 200 to 400€/MWh, whereas offshore wind is currently at about 170€/MWh [6].

5. Integrating marine renewable energy with the oil & gas sector
A meaningful market implementation of marine renewable energy needs to be coupled to the already existing and more mature technologies, namely the ones developed for fields with a longer track-record in history. Therefore, the Marine Energy Group of FEUP also fosters research relating oil and gas infrastructures with marine renewable energy technologies. A good example is given in the studies developed to assess the potential of wave energy to supply oil and gas platforms at remote locations where electricity supply from onshore grids or local gas turbines is generated at a considerably high cost. The new techno-economic models developed to assess and scale WECs to match the local wave climate at the platform’s deployment site and pre-design the wave farm showed very interesting prospects [6], especially when hybrid technologies, combining solar and wave energy harvesting, are used [7].

Coupling the novel fields of marine energy research with traditional ones enhances the integrated development of new harvesting technologies, while diluting the market entry costs and simultaneously benefiting from the acquired knowledge and experience from more mature fields of research. Additionally, expenditures get reduced due to important cost sharing, as the deployment, transport, installation and maintenance of novel concepts might be partially accounted for as part of the investment already needed for oil and gas infrastructures. Evident examples of potential cost sharing are the investments made in the offshore foundations.

6. Protecting offshore structures
The idea of placing offshore structures and foundations in marine remote locations to capture the vast sea energy potential has much appeal as complexity. Hence, the reliable safety and operation of these structures have been the subject of one of the research lines most preferred by the industry’s stakeholders. Optimising the cost of the foundations and their performance under extreme sea conditions remains an important part of the overall capital needs. A considerable part of the costs of offshore foundations and structures lies in the necessary protective measures to account for the soil-structure-fluid interaction. From this interaction, one of the most important sources of structural instability is scouring causing loss of soil around the foundation, which leads to the loss of momentum bearing capacity and eventual collapse due to fatigue and resonance. Aiming at optimised foundations, the Marine Energy Research Group has been leading several projects related to the optimisation of scour
protection. For example, in the ORACLE project, a risk analysis methodology was developed to implement a probabilistic design of scour protection. The novel methodology is focused on optimised dynamic scour protection, which enables the use of rubble-mound material with smaller dimensions than the one applied in statically stable protection [8]. The ORACLE project also identified synergies among other international projects on scour research in which the Marine Energy Research Group takes now an active role, such as, for instance, the PROTEUS project [9], which addresses the optimisation of scour protection by means of large-scale physical modelling activities performed in the Fast Flow Facilities (Figure 6) at HR Wallingford, UK.

Figure 6 – Scour at a monopile foundation for offshore wind turbine. Left: scour hole at monopile scaled at 1:50. Top right: Large-scale (1:16.7) scour protection being tested at the Fast Flow Facilities of HR Wallingford during Proteus project [9]. Bottom right: Digital Terrain Models of a scour protection used to derive scour depths.

7. Conclusions
Marine renewables are expected to largely contribute to the Global Society’s efforts to achieve a low carbon economy. Additionally, they can represent an unparalleled opportunity to counteract climate change effects. The theoretical potential of Marine Renewable Energy exceeds 151,300 TWh/yr, excluding offshore wind energy, marine biomass or offshore solar energy. Values that are even more interesting are achieved if excluded components are added, e.g. offshore wind energy has an estimated technical potential of 192,800 TWh/yr [10]. These values combined largely exceed the World’s primary energy consumption. However, the practical exploitation of the untapped vast energy resources at sea is still in need of further contributions that may lead to significant reduction in the capital, operational and maintenance costs. Some of the research lines and projects hereby presented provide new ways towards that goal. An ambitious goal indeed, that requires a difficult journey down a sinuous lane, which, in time, will hopefully result in a sustainable Society, where energy needs are met by clean and renewable energy sources.

Acknowledgements
The i.nano.WEC project was supported by Fundo Azul (FA 02 2017 002) and coordinated by inanoEnergy. SE@PORTS project was funded by OCEANERA-NET (OCEANERA/0004/2016) and coordinated by INEGI. PORTOS project (EAPA_784/2018) is co-financed by Interreg Atlantic Area
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