

Numerical investigation of a novel hybrid wind-wave system and its variable pneumatic chamber volume control

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Abstract—This work presents a numerical investigation of a novel control strategy for a new hybrid wave-wind energy floating platform. It comprises the variation of pneumatic chamber volumes to maximise wave power production. The numerical model is implemented in the object-oriented non-casual language Modelica. Seven case studies were designed and analysed for the OctaPlat, which is a concrete-based wave energy platform comprising five oscillating water columns, which can be used as a multipurpose floating platform, including floating wind. This capability makes the OctaPlat a potential hybrid wind-wave platform. However, this study focuses on increasing wave production through a control strategy that combines air turbines as power take-off systems for oscillating water columns with air chamber volume variation. This study does not consider the wind energy production of the hybrid system. A sensitivity analysis of pneumatic chamber volume variations and air turbine size variations is performed to explore the applicability and effects of this strategy as a way to maximise OctaPlat's power output under operational conditions. Results show that there is a wide range of possibilities for increasing conversion efficiencies and power output. The best performing scenario achieved a 33% increase in mean annual capture width ratio compared to the base case, while remaining within the platform's physical constraints. The results highlight that adaptive volume control, especially when combined with optimised turbine sizing, offers a promising strategy to improve energy output. The optimal volume configurations were found to vary across sea states, reinforcing the importance of tailoring control strategies to local wave conditions.

Index Terms—Oscillating water column; multipurpose platform; wind-wave hybrid systems; pneumatic chamber variable volume control; Modelica.

I. INTRODUCTION

OFFSHORE renewable energies have emerged as an innovative strategy to achieve carbon neutrality by 2050. The European Union's (EU) targets expect ocean energy, such as wave and tidal energy systems and floating wind power, to reach roughly 40 GW by 2050 [1]. Hybrid systems that combine wind and wave are a promising solution, as they combine

wind, a mature technology that is growing on the market, and wave energy converters (WEC), which have great potential given the high water resources available but have not yet reached commercialisation due to their complexity and high levelised cost of energy (LCOE) [2].

There are a few types of WEC technologies, namely oscillating water column (OWC) devices. This type of device is the most studied and developed to this date, yet improving efficiency and adaptability to irregular wave conditions remains an obstacle [3]. One of the means under study to overcome this barrier is the control strategies applied to the different subsystems, such as power take-off (PTO), airflow regulation and structural dynamics.

According to the review paper by Wang *et al.* [4], WEC control strategies can be categorised into three major categories, according to their position in the energy conversion chain: hydrodynamic control, PTO control, and grid-side control. The first involves adjusting the geometry, inertia, or movement restrictions of the primary energy absorber, namely changes to the shape or buoyancy of the structure. PTO control deals with the mechanical or electrical manipulation of certain variables, such as force, speed, torque, pressure, and airflow. These are implemented through turbines, hydraulic actuators, or flow control valves. Within this category of control, different strategies have been proposed: Passive control applies fixed damping to absorb energy without the need for external energy injection. Decutching control is also a strategy that has been studied whereby, by switching off the generator, using bypass valves, or blocking the turbine shaft, losses can be avoided when the airflow is weak or counterproductive (e.g., reverse direction in Wells turbines), and efficiency can be maximised by only operating when the available power is sufficient. There are also more complex strategies, such as model predictive control (MPC), which uses real-time forecasts of system dynamics and wave conditions to optimise control actions.

This study aims to investigate the optimal configuration of turbine diameter and air chamber volume for each OWC in order to maximise the energy conversion of a novel hybrid wind-wave floating platform. Furthermore, it aims to infer the efficiency of a novel type of control, which varies the air volume of each air chamber for a set of sea states located in the port of Leixões.

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