Geometry-Inclusive Controller Co-Design: Inerter and Heave Plate Optimization for a Self-Reacting Point Absorber

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Key messages

- Wave energy is underutilized globally due to its high cost versus wind and solar.
- Adding a heave plate to a WEC can boost potential power production up to 5x in some sea states.
- Co-designing WEC geometry with its controller, tuned to site conditions, boosts energy output.
- An inerter, an inertial control device, can greatly widen a converter's efficient frequency range.
- These findings support location-specific, geometry-inclusive optimization of wave energy tech.

Overview and Importance: The Cost Barrier to Wave Energy

Global demand for clean, locally produced energy is accelerating (International Energy Agency, 2025). The rise of data centres, electric vehicles, and geopolitical pressure to reduce reliance on energy imports are all pushing regions to diversify their electricity sources (International Energy Agency, 2022). Ocean wave energy is a compelling but largely untapped option: it is globally distributed, available close to population centres, and highly predictable compared to wind. Yet wave energy contributes only a negligible fraction of global electricity generation today (European Commission, 2025).

The primary obstacle is cost. The levelized cost of energy (LCOE) from wave energy converters (WECs) remains far higher than competing renewables (Guo et al., 2023). While economies of scale will eventually help, meaningful gains in conversion efficiency are needed first. This work investigated one promising avenue: modifying the physical geometry of a WEC in coordinating with design of its controller to improve how efficiently it captures energy from the ocean (Ringwood, 2025).

Key Discoveries and Intellectual Merit: Pairing Geometry with Control

This study examined a two-body, heave-only self-reacting point absorber (SRPA). An SRPA is a class of WEC in which a floating buoy and a submerged spar move relative to each other to generate power. Four variants of the spar were designed, each fitted with a progressively larger heave plate (a disc attached to the bottom of the spar). Heave plates increase the added mass and radiation damping of a device, qualities that govern how it interacts with passing waves.

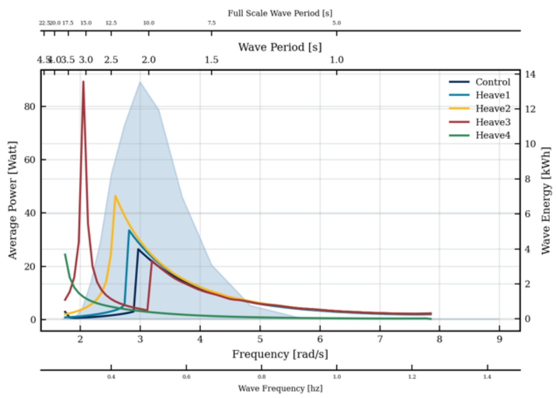

Figure 1: Potential average power capture for five WEC designs with heave plates of increasing size (1 = smallest, 4 = largest). The wave energy spectrum off Nootka Island is shown in blue.

For each WEC geometry, an inertial device called and inerter which uses a force proportional to the acceleration between the float and spar was added as a control element. The inerter's design parameters were then optimized using a genetic algorithm, with the explicit goal of expanding the range of wave frequencies over which the WEC can extract energy at or near its theoretical maximum. The inerter was optimized specifically for each separate WEC-heave plate configuration, not independently. This is the essence of controller co-design.

The theoretical performance of each WEC-inerter pairing was then evaluated against measured wave energy spectra from Nootka Sound, off the west coast of Vancouver Island. The results show that having a specifically sized heave plate effectively shift the device's peak hydrodynamic response toward lower frequencies, which better aligns with the dominant energy-containing waves that occur near Nootka Island.

Broader Impact and Next Steps: What This Means for Future WEC Design

This work establishes that WEC geometry is not simply a structural or stability consideration, it is a performance lever that should be optimized alongside the controller, and ideally tuned to the wave climate of a specific deployment site. A WEC designed for the swells off Nootka Sound should look different from one designed for the North Sea or the Bass Strait.

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The heave plate is one example of a geometric feature with strong, predictable effects on hydrodynamic behaviour. Future work will explore other design elements: hull shape, draft, diameter, and incorporate geometry directly into the optimization loop. Longer-term, the goal is a data-driven design process where target hydrodynamic coefficients for a given sea state can be translated directly into a recommended WEC geometry, accelerating the path to cost-competitive wave energy for coastal communities.

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