Combined Offshore Wind, Wave, Storage System Power and Cost Predictions

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The motivation of this work is to significantly increase the power generated by an offshore wind turbine installation and to optimize its renewable power integration into the electrical grid. Our general strategy for achieving this is to combine an oscillating water column (OWC) wave energy converter and an offshore renewable energy storage (ORES) device to the offshore wind installation.

In OWCs, a chamber has an inlet submerged below the water surface and an outlet open to the ambient air above the water surface. Wave motion at the inlet pushes air through the outlet. The outlet is typically fitted with a Wells turbine, which rotates due to the air flow past it. The Wells turbine blades are designed so that both outwards and inwards air flows rotate the turbine in the same direction. This mechanical rectification greatly increases the robustness of the WEC to different sea states with different wave characteristics than compared to a point absorber system (a "buoy" wave energy converter).

Ten years of on-shore OWC installations have proven the machines to be well-suited for the sea environment with few moving parts and dynamical robustness to different sea states. The system may be installed at the same time as a new FWT or retrofit to an existing FWT. The FWT and OWC can share the same mooring and electricity transmission lines, greatly reducing the cost of the wave energy converter (mooring and transmission lines typically comprise 28% the cost of a 3.6 MW FWT and 60% the cost of a 1 MW floating OWC).

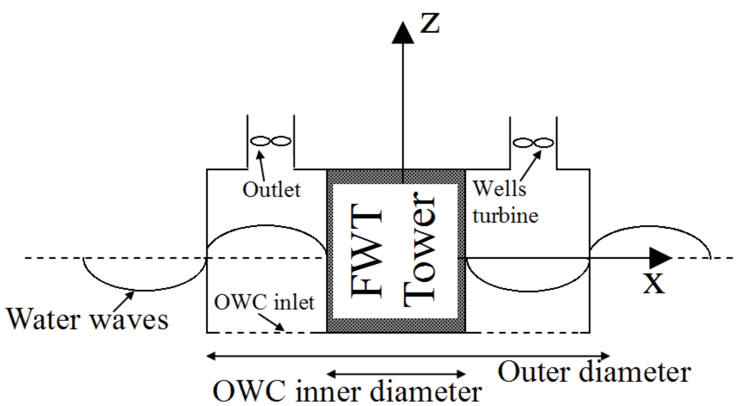

Figure 1: Sketch of a design where an array of oscillating water columns encircles a floating wind turbine

In this work, we use a first-order model of the OWC hydrodynamics and thermodynamics to predict the power generated by the OWC turbine. We consider both a linearized model for frequency-domain analysis and a full nonlinear model that is numerically simulated in MATLAB. We further use linear hydrodynamic theory to predict the lateral and vertical forces transmitted by the OWC to the FWT based on the OWC geometry and the interface between the OWC and FWT.

Additionally, we model at a system level the combined FWT-WEC-ORES-transmission line device. We note that ocean wave power is less variable than wind power, and may lessen variations in the FWT-WEC device generated power. We assign to the ORES device an energy storage capacity, and power absorption and release efficiency. We model transmission line losses for a given line length. We consider typical power demands of electric grid customers.

The overall goal of this study is to minimize the levelized cost of energy (LCOE) for the offshore device. We maximize the power generated by the OWC and make its performance robust to different sea states via controls or intentional nonlinear geometry. We consider different OWC configurations for reducing the hydrodynamic heave and lateral forces induced on the FWT tower. An optimal OWC design requires no or minimal additional mooring lines to the FWT system. Additionally, it is desirable that the offshore FWT-OWC-ORES system performs well in terms of its source-to-grid power efficiency, power supply-to-power demand matching, and minimized transmission line cost. Finally, we predict the capital expenditures, lifetime, and maintenance costs of the device for computing its LCOE.