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Mechanics and materials in the design of symbiotic offshore energy harvesting systems

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ABSTRACT

A single type of energy harvesting device may be too expensive to deploy, but if it can operate symbiotically (Slocum, 2014) with another, the combined cost of energy might be acceptable. As an example, consider offshore wind turbines, which hope to use their greater capacity factors to compete with land-based turbines; however the structures can become prohibitively expensive if they must be placed further offshore to avoid opposition from shoreline residents. To reduce overall costs of energy, this paper will explore adding wave energy and uranium-from-seawater harvesting devices to offshore wind turbine structures.

WAVE ENERGY

With stronger winds, larger turbine sizes, and plenty of space versus on-land, offshore floating wind turbines (FWT's) have the potential to satisfy significant energy demand with renewable power (Kluger, 2015). However, a 5 MW floating wind turbine capital cost runs as high as $20.7 million, leading to an energy cost of $0.20/kWh, four times that of natural gas (Myhr, 2014). This cost is largely driven by the structure's need to withstand large wave forces that act on the floating platform. On the positive side, wave power is a predictable, constant, and energy-dense renewable resource. The energy resource in waves may be as high as 50-60 kW/m average annually. Despite these promising qualities, electricity from ocean wave energy converters (WEC's) is currently much more costly than other sources, ranging from $0.28-$1.00/kWh. 27% of a typical WEC's cost due to permitting, electric transmission lines, and mooring lines. 37% of a typical WEC's steel is for a supporting frame (Yu, 2015).

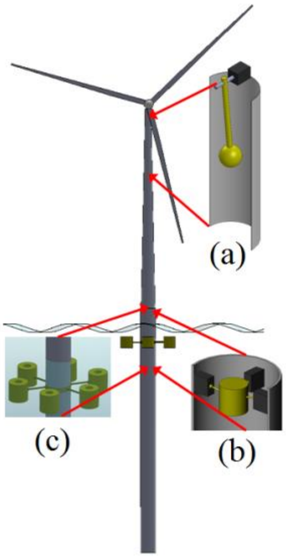

Figure 1: OC3-Hywind 5 MW floating wind turbine with various attached wave energy converters (WEC's): (a) Surge-mode tuned mass damper in the nacelle, (b) Heave-mode turned mass damper in the floating platform, and (c) Array of external heave-mode wave energy converters attached to the platform.

Symbiotically, a WEC could act as a tuned mass damper or ocean wave absorber to reduce wave-excited platform motion, allowing the platform and tower to be built with less steel at lower cost. In addition, a WEC attached to a floating wind turbine could share permitting, transmission, and mooring line costs with the wind turbine, and eliminates much of the WEC steel frame. Predictable and robust wave power may then supplement the wind power harvested

Several WEC configurations and parameters are considered to reduce the total FWT-WEC cost of energy: an internal tuned mass damper or external wave energy converter; with hydraulic, Wells turbine, or non-electricity-producing power take-off mechanisms, as illustrated in Figure 1. The wave energy converters can have the power dissipative elements at their junction points with the floating wind turbine. The external array (c) can have a Wells turbine in the WEC body, exposed to incident waves.

To optimize the combined system, we model the coupled equations of motion for a floating wind turbine platform, flexible wind turbine tower, and attached WEC in the frequency domain. Using response amplitude operators, we estimate the platform motion, tower stress, and WEC power over 20 years in a typical wind-wave environment. We estimate the wave energy converter's cost based on its power capacity, complexity factor, and steel mass.

URANIUM HARVESTING

Uranium is present in the world's oceans as dissolved ions at a uniform concentration of approximately 3.2 ppm (Oguma, 2011), which, over the total volume of the oceans, amounts to approximately 4.5 billion metric tons, about 1000 times more than exists in conventional terrestrial uranium reserves (Tamada, 2006). Current methods of adsorbing uranium from seawater use chelating polymers, as they have been found to be the most promising in terms of cost, adsorption capacity, and environmental footprint (Kim, 2013, Zhang, 2003, Seko, 2003, Anirudhan, 2011). Chelating polymers are submerged in seawater until the amount of captured uranium approaches the fiber's adsorption capacity. Uranium and other elements that have bonded to the polymer are then stripped off in an elution bath. This bath process may be repeated multiple times before the polymer is regenerated by an alkali wash which frees the adsorbent's functional groups, allowing it to be reused. Finally, the output from the elution process undergoes purification and precipitation to produce yellowcake in similar processes as mined uranium. Initial deployment schemes utilized arrays of adsorbent fibers braided into buoyant braids and laid out along the ocean floor (Tamada, 2006, Schneider, 2014). However, the periodic retrieval and redeployment of the fibers required the use of ships, resulting in an extremely costly system. By deploying the adsorbent braids off of an offshore wind turbine, it was estimated that costs could be significantly reduced (Picard, 2015, Haji, 2016, Byers, 2016).

However, in general, uranium-adsorbing materials have inherently low tensile strength and durability, posing significant problems for deployment of adsorbent braids in a harsh ocean environment. To overcome this, we developed a two-part system utilizing a hard, permeable outer structural shell that houses an inner adsorbent, thereby allowing for the decoupling of the mechanical and chemical requirements of an offshore uranium harvesting system (Haji, 2015). Figure 2 depicts one shell design. This system allows for the chemistry of the inner material to be optimized for higher adsorbent capacities, while the mechanical properties required of the device are achieved by the hard, permeable outer structural shell. The resulting overall system is more cost-effective for implementation. In this paper, we present the material properties of the outer shell, the adsorbent fiber, and a mooring rope that may be used to connect the two into a ball-chain system or net that is then incorporated into a machine that works offshore to harvest uranium from seawater.

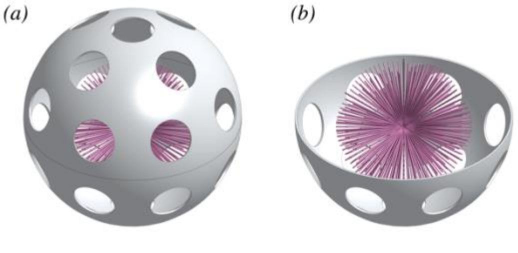

Figure 2. Decoupling of mechanical and chemical requirements with a tough, outer protective sphere encapsulating a soft, inner adsorbent (Haji, 2015).

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