Wave Energy Developments at Oregon State University

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1. Introduction

The solutions to today's energy challenges need to be explored through alternative, renewable and clean energy sources to enable a diverse national energy resource plan. A significantly untapped renewable energy source exists in the world's oceans: it is estimated that if 0.2% of the oceans' untapped energy could be harnessed, it could provide power sufficient for the entire world. Ocean energy exists in the forms of wave, tidal, marine current, thermal (temperature gradient) and salinity. Among these forms, significant opportunities and benefits have been identified in the area of wave energy extraction. Waves have several advantages over other forms of renewable energy such as wind and solar, in that the waves are more available (seasonal, but more constant) and more predictable, thus enabling more straightforward and reliable integration into the electric utility grid. Wave energy also offers much higher energy densities, enabling devices to extract more power from a smaller volume at consequent lower costs.

2. Wave Energy Developments at Oregon State University

OSU's multidisciplinary wave energy team continues to pursue wave energy developments in three thrust areas: 1) researching novel direct-drive wave energy generators, 2) developing an action plan for a National Wave Energy Research and Demonstration Center in Oregon, and 3) working closely with the Oregon Department of Energy (ODOE) and a variety of stakeholders to promote Oregon as the optimal location for the nation's first commercial wave parks.

OSU's direct-drive research focuses on a simplification of processes, i.e. replacing systems employing intermediate hydraulics or pneumatics with direct-drive approaches to allow generators to respond directly to the movement of the ocean by employing magnetic fields for contact-less mechanical energy transmission, and power electronics for efficient electrical energy extraction. The term "direct" drive describes the direct coupling of the buoy's velocity and force to the generator without the use of hydraulic fluid or air.

The Oregon State Wave Energy team's research and development goals are driven by the important issues of survivability, reliability and maintainability, in addition to efficient and high quality power take-off systems. OSU is a prime location to conduct ocean wave energy research, noting the following strategic facilities:

- OSU is the home of the nation's highest power university-based Energy Systems laboratory, the Motor Systems Resource Facility (MSRF), with a 750kVA dedicated power supply and full capabilities to regenerate back onto the grid (See Fig. 1).

- OSU is the home of the O. H. Hinsdale Wave Research Lab (WRL) with world-class wave tank facilities including a 342 ft. wave flume (See Fig. 2).

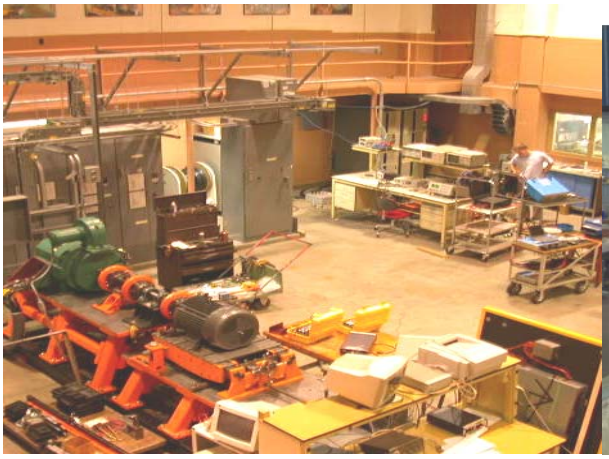

Fig. 1 OSU's MSRF.

Fig. 2 OSU's O. H. Hinsdale WRL.

The Oregon State University Wave Energy team is developing several novel direct-drive prototypes including a Permanent Magnet Linear Generator Buoy, a Permanent Magnet Rack and Pinion Generator Buoy, and a Contact-less Force Transmission Generator Buoy. These buoys are designed to be anchored one to three miles offshore, in typical water depths of greater than 100 feet, where the buoys will experience gradual, repetitive ocean swells. Inside the Permanent Magnet Linear Generator Buoy, the wave motion causes specially designed electrical coils to move through a magnetic field, inducing voltages and generating electricity. In the Permanent Magnet Rack and Pinion Generator Buoy, linear to rotary conversion is being developed as an extension of the concept of permanent magnet gears. The Contact-less Force Transmission Generator Buoy exhibits linear force transmission using large, high-strength permanent magnets configured in a "piston." The motion of the piston is then transformed to rotation using a ball screw to drive a permanent magnet rotary generator. Advanced designs of these prototypes are also being developed to achieve higher efficiencies and power output performance. The OSU researchers are also interested in small scale wave energy generators, which could be integrated into boat anchor systems to power a variety of small craft electronic devices. These similar small-scale systems could enable ocean data collection and monitoring buoys to become self-powered. To comprehensively test, evaluate and advance wave energy conversion devices, OSU is also designing and building a Linear Test Bed in their MSRF, which is discussed in more detail in Section 3.

The combination of key facilities at Oregon State University, ongoing successful wave energy research, and the tremendous wave potentials off the Oregon coast has led the OSU Wave Energy team to pursue the formation of a National Wave Energy Research and Demonstration Center in Oregon. This Center is strategically necessary for the U.S. to keep pace with wave energy developments around the world, in what is projected to become a rapidly developing new set of industries. Ocean wave energy extraction technology is currently in the preliminary stages of development, where wind turbines were approximately 15-20 years ago, with several topologies developing, and no clearly superior engineering solutions yet established. This National Wave Energy Center would enable the acceleration of research toward optimal topology standards, similar to the wind turbine research process which led to the predominant horizontal-axis, three-blade turbine design. Fortunately, several factors such as advanced technologies and materials, and lessons learned from other renewable industries, offer encouraging predictions that the "catch-up" time for ocean wave energy can be accelerated. The

National Center will also encourage research involving other important wave energy issues including environmental impacts, optimum device spacing/placement, buoy mooring and navigational identification etc.

Fig. 3 shows a conceptual wave park illustration, highlighting OSU's first wave energy prototype of its permanent magnet linear generator. As shown in Fig. 3, each buoy would have a power cable dropping down along the tether to the anchor, which would then be routed to a central junction box located on the seafloor at the front of the wave park. At the central junction box, the unregulated voltages from all of the buoys could be "combined" and conditioned as regulated dc for delivery to the shore through a single submarine cable. At the shore substation, the dc power provided by the wave park could be inverted to ac, and connected to the grid. The Oregon coast has excellent wave energy potentials, where wave heights in the winter average 3.5 meters, which converts to 50kW per meter of crest length (each coastal home is about 1.3 kW). During the summer, average wave heights are 1.5 meters, which converts to 10kW per meter of crest length. Considering an overall average of 30kW/m, and an Oregon coastline of 460km, the total Oregon coast raw Wave Energy potential is in the range of 13,800MW. The average electrical energy consumption in the state is about 5-6000 MW, thus the 13,800 MW of raw wave energy can have a significant impact on Oregon's renewable energy portfolio.

The OSU researchers, along with Oregon Sea Grant, realized the significant need for partnership and collaboration with fishermen and crabbers and formed a Port Liaison Project team of commercial fishing industry experts/cooperators to aid in wave park siting and ocean technical expertise. Both input from fishermen and experiences from the Oregon Fishermen's Cable Committee are essential for making the leap from lab to a "real-world scenario" in the ocean. OSU has also been working closely with Oregon Department of Energy (ODOE) to promote Oregon as an optimal location for the nation's first commercial wave parks. The manufacturing and fabrication would be performed locally, meaning job opportunities for coastal Oregonians. At about one to three miles offshore, the parks would be virtually invisible from the beach, thus preserving views, but close enough to make anchoring and transmission feasible. The buoys would be placed in water depths of 100 - 200feet; before the waves start to break and dissipate their energy.

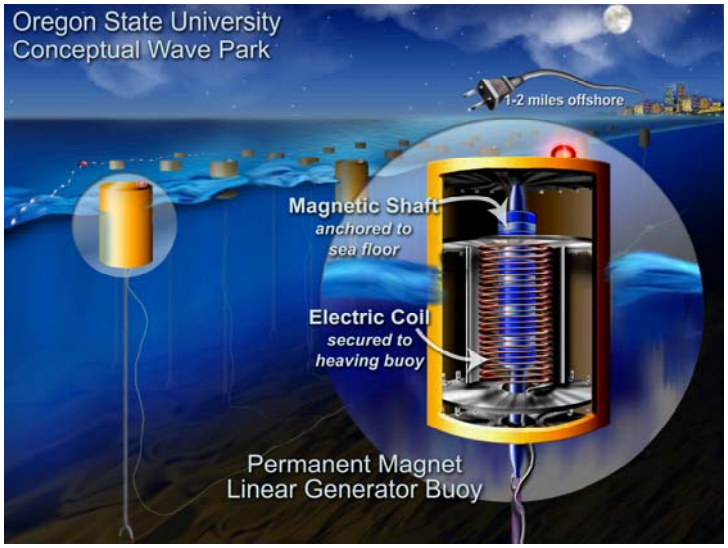

Fig. 3 Oregon State University Conceptual Wave Park.

3. Linear Test Bed Development

OSU's Wave Energy team has recognized that in order to advance and optimize wave energy devices, they need to upgrade their Energy Systems lab/facility with Wave Energy Linear Test Bed (LTB) Equipment. The LTB would also significantly increase OSU's Wave Energy research capabilities as they pursue a National Wave Energy Research and Demonstration Center. The National Demonstration Center is planned to be located off Lincoln County (potentially off Newport, OR), with land-based facilities that could be integrated with ongoing activities at the Hatfield Marine Science Center.

The LTB (see Fig. 4) is designed to generate the relative linear motion created by ocean waves to optimize wave energy device technologies. For example, the LTB will create the linear motion between a vertically oriented center "spar" and the active components of a surrounding "float". Thus, the LTB will enable the dynamic and controlled testing of wave energy devices, using captured wave profiles from ocean monitoring buoys, while simulating the actual response of ocean waves. In detail, the mechanical machine oscillations in the vertical axis will simulate sinusoidal vertical velocity, predetermined velocity profiles, or dynamically controlled force interactions to simulate the real response of the buoy in ocean waves. Simulating ocean waves requires very high forces. For this LTB system, driving forces of up to 20,000N (4500 lbs) at speeds of 1m/s are required.

The LTB system will be comprised of one (1) vertical axis (Z) of servo controlled CNC (computer numerically controlled) motion for moving the wave energy Device Under Test (DUT). A servomotor, through timing belts, will be used to move the LTB carriage to drive the active float up and down. The outer active float will be attached through dual load cells to the driving arm of the LTB, with servo loop integration. Rollers on a steel track will provide guidance for the carriage. The base has a gimbal mounting for the center spar and a removable pallet for loading and unloading the DUT. An upper gimbal mount will be used to attach the top of the DUT to the Z carriage. (Note, the active float of the buoy is mounted with a gimbal mount to tolerate dimensional and alignment variation of the DUT). Adapter plates will be used for different size wave energy devices. A versatile PC-based motion controller will be used to control all motion. A Graphical User Interface (GUI) will provide access for setup, motion profiles and overall operation of the machine.

4. Conclusions

Recent advances demonstrate that there is reason to hope that ocean wave power may become a new, reliable and clean source of affordable renewable energy. Oregon is poised to lead the nation and the world in wave energy development. Oregon has the wave resource, the expertise through collaboration including tremendous university, industry, utility and community support, and the utility infrastructure along the coast to deliver this clean, renewable power to the grid.

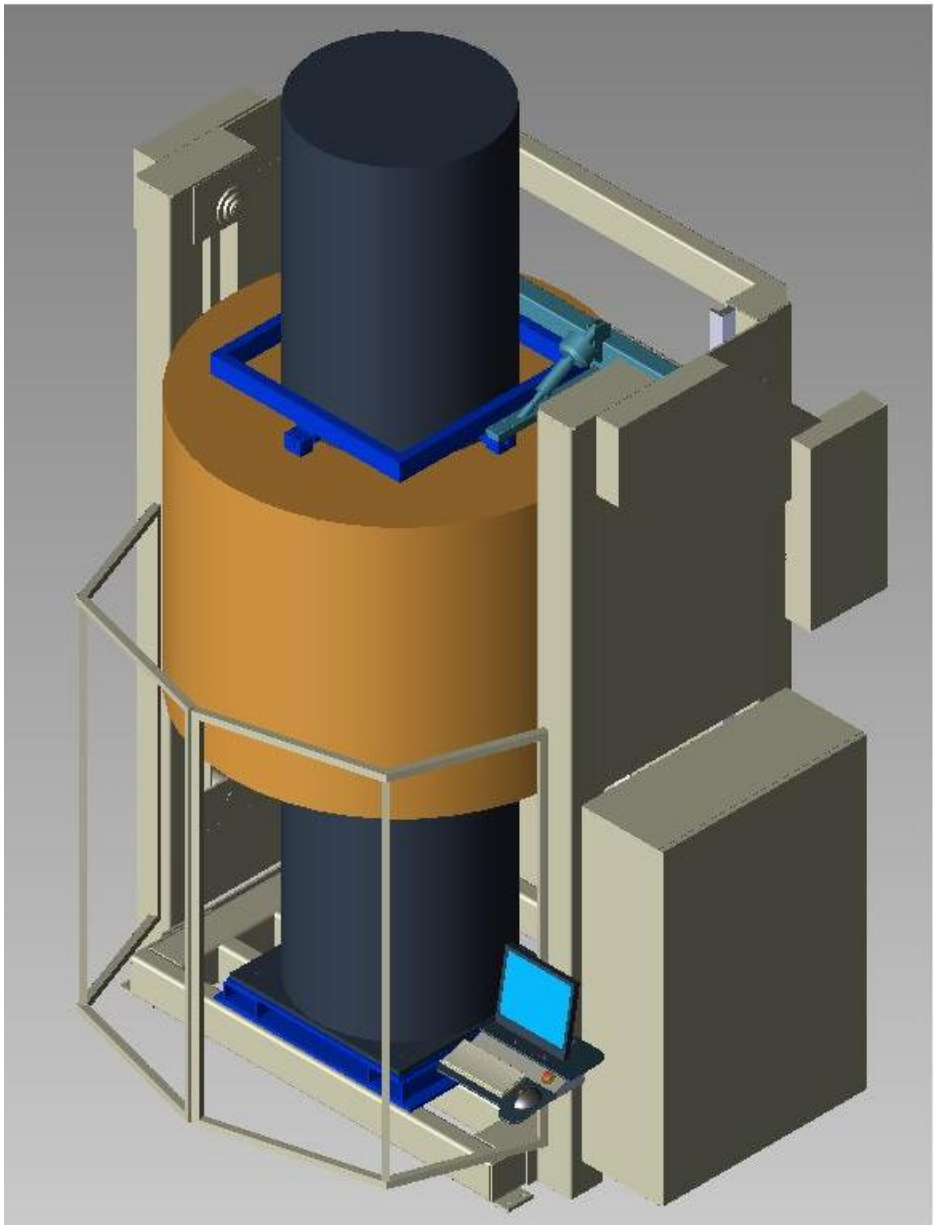

Fig. 4 OSU's Planned Wave Energy Linear Test Bed.