Ocean Wave Power:
Opportunities and Implications

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ICPC Topic: Evolving Uses (e.g. Wavefarms)

Abstract

This paper reports on the technological advances in the field of wave energy extraction and the research being conducted at Oregon State University (OSU) to develop advanced wave driven generators. OSU's Wave Energy team is also pursuing the formation of a U.S. Wave Energy Research, Development and Demonstration Center in Oregon. A wave energy park associated with the Center will enable research and testing of wave energy generators, as well as associated power take-off systems and environmental issues. The OSU Wave Energy team is also working with the Oregon Department of Energy to promote Oregon as the optimal location for the United State's first commercial wave parks. Wave energy power cables are a new type of cable in the Eastern Pacific. Due to the unique nature of wave energy parks, cable protection efforts will be tailored to prevent interaction and damage to the wave generator buoy interconnection cables and the main shore feed power cables. OSU is working with Oregon Sea Grant and the Oregon Fishermen's Cable Committee to develop cable protection strategies that minimize impacts to the fishing industry and provide security to the cables. Implications of zoning ocean areas will be discussed.

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 to provide reliable power. Wave energy also

offers much higher energy densities, enabling devices to extract more power from a smaller volume at consequent lower costs.

Wave Energy Extraction Technologies

The world's first wave energy device patent was registered in 1799 by Girard, in Paris. After more than 200 years of development, there are currently more than 1500 wave energy device patents. Historically, there have been two booms of interest in the research of wave energy, corresponding to the 1970s oil crisis and pollution concerns as well as concerns regarding natural resource reserves since the mid 1990s. Depending on the distance between the conversion devices and the shoreline, wave energy systems can be classified as shoreline, nearshore and offshore extraction systems.

Wave energy devices that are developing around the world include the Ocean Power Technology (OPT) "PowerBuoy," Ocean Power Delivery (OPD) "Pelamis," Aqua Energy's "Aqua Buoy," Wavegen's "Limpet," Energetech's Oscillating Water Column "(OWC)," etc.

Wave Energy Developments at Oregon State University

Oregon State University (OSU) has developed a multidisciplinary wave energy team investigating novel "direct-drive," offshore, wave energy extraction approaches. OSU's 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 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) is co-directed by Annette von Jouanne and Alan Wallace 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.

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 U.S. Wave Energy Research, Development and Demonstration Center in Oregon. The Center would be strategically located at OSU for research and development (through the MSRF and the WRL), with a research/demonstration site off Newport, OR, where land-based facilities could be integrated with ongoing activities at the Hatfield Marine Science Center (HMSC). This National Wave Energy Center is strategically necessary for the U.S. to keep pace with the European Marine Energy Center (EMEC) in the development of renewable wave energy resources 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, materials, and lessons learned from other renewable industries, offer encouraging predictions that the "catch-up" time for ocean wave energy can be accelerated.

Figure 3 shows a conceptual wave park illustration, highlighting OSU's first wave energy prototype of its permanent magnet linear generator. Full scale wave park buoys could be 10 meters tall (33 feet, and fairly neutrally buoyant), and 6 meters in diameter (20 feet), and capable of producing up to 250kW of power. An average coastal home consumes 1.2 – 1.5kW, and including a capacity factor of 0.5, each buoy would be capable of supplying approximately 90 homes with power. 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 would 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 would be inverted to ac, and connected to the grid.

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. Input from fishermen and crabbers 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. Several developers have stepped forward, with incrementally planned phases starting at 2 MW and then scaling up to the 20-30MW range. The manufacturing and fabrication would be performed locally, meaning job opportunities for coastal Oregonians. The ODOE estimates that as wave energy develops over the next several years, over two hundred high paying jobs could be created. At about one to three miles offshore, the park will be invisible from the beach, thus preserving views, but close enough to make anchoring and transmission feasible. 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.

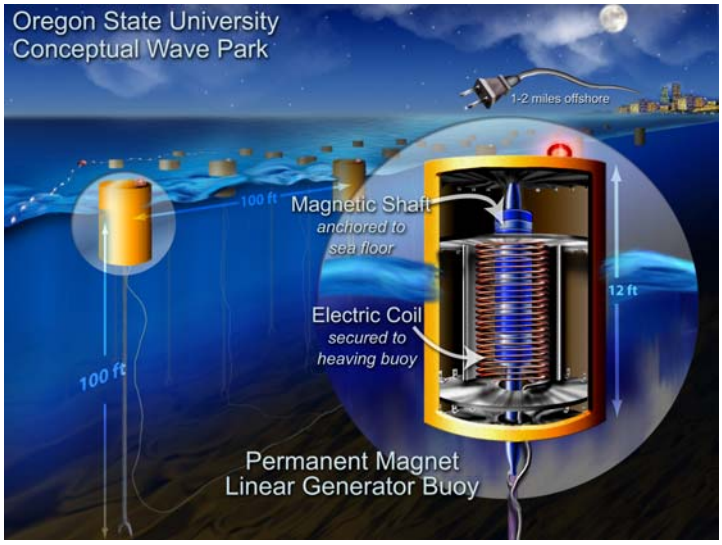

Fig. 3 Oregon State University Conceptual Wave Park.

OSU partners with Oregon Sea Grant

Wave energy researchers at OSU recognized that collaboration with the fishing fleet was an important part of the planning process. Annette von Jouanne and Ken Rhinefrank have been working with Oregon Sea Grant to get input from local fishermen through the Port Liaison Project (PLP) team collaboration process. OSU first sought input from the PLP team of industrial fishermen to determine the lowest impact site for a wave park off the coast of Gardiner, Oregon. In addition to helping OSU identify optimum wave park sites, the PLP team is providing technical expertise on buoy tethers, bottom anchors, mooring, maintenance of equipment, etc.

Finding the optimum site location at this 2 to 3 mile range is an important first step in wave energy park siting. This location from shore is quite often a soft sand muddy bottom that is ideal for the crabbing fleet. The competing interest of prime crabbing grounds versus the developers' need to reduce the electrical distribution distance to reduce costs, will require creative solutions.

OSU Works With Oregon Fishermen's Cable Committee

The Oregon Fishermen's Cable Committee (OFCC) has collaborated with undersea fiber optic cable owners in Oregon for over seven years. The OFCC mission is to encourage communication, coordination and cooperation between the fishing industry and owners of submarine cables. The OFCC has agreements covering six cables on the Oregon Coast. The proposed wave energy park would create a need for a new type of agreement between the fishing industry and the wave energy park developers. In a few respects, the wave energy power cables would be similar to the other cables the OFCC has agreements on. For example:

- The placement of cables in the fishing grounds will require cooperation between the fishing industry and the developers to achieve minimal impacts to both.
- Fishing industry support can help to expedite the permitting process by addressing issues of concern prior to submitting the permit applications.

In other respects, the wave energy cable is a new type of cable deserving a unique cable/fishing agreement. Notable differences are as follows:

- Previous OFCC agreements preserve traditional fishing opportunities, negating any need for mitigation of lost fishing opportunity. With a wave energy park, some fishermen and crabbers may have a loss of fishing ground, creating the possible need for mitigation.
- The area/footprint of the wave energy park may become a "no fishing" zone. However, wave parks could coexist with designated marine reserves and sanctuaries.
- The length of the cable between the shore and the wave energy park is quite short–likely in the order of one to three miles–having a much lower potential for trawler contact.
- It is likely that the creation of the wave energy park will permanently close sections of the ocean (the footprint of the wave park) to salmon trolling, trawling and crab fishing. One of the principle focuses of the previous OFCC agreements has been the shared use of the seabed. The cables extending from the wave park to shore will involve similar agreements, however, the actual wave park footprint will require a departure from the earlier agreements.
- Crab pots frequently "drift" due to the harsh environment. Inevitably, some of this gear will end up within a wave park. Establishing reasonable boundaries to minimize this loss of equipment will be needed. If equipment is lost due to a wave park, provisions for compensation to the crabbers may be needed. Safe methods for equipment removal from the wave park will also be needed.
- Significant portions of the existing OFCC cable agreements concerning the sacrificed gear fund, ROV inspections, as-built coordinates, cable burial, and release of liability may not apply, or would have substantially different terms.
- Unlike buried fiber optic cables, any unburied wave energy cables will have ongoing impacts to fishermen, including fishermen not part of the OFCC's trawl fleet.

- If a wave energy project becomes defunct, ocean users will continue to have major impacts until the generators and anchors are removed. An adequate bond to fully cover the cost of removal should be required of project developers.

Cable Protection

The cable protection program will likely be based on the following assumptions:

1. The density of the wave generator buoys will prevent trawling from occurring in the wave park.
2. Crab fishermen will be encouraged to fish outside of the park.
3. Policing of any "no fishing" zone should be from within the fleet itself.
4. OSU will utilize the OFCC and PLP industry cooperators' to build trust, respect, and cooperation. Using this foundation, fishermen who bear the costs of this development may share in the benefits of the project. For example, local vessels might be utilized to tow wave generator buoys into port for maintenance, recover any that get loose, deploy anchors, etc.

Ocean Zoning

Creation of a wave energy park will have the effect of "ocean zoning." Permitting of a park will, by necessity, create an exclusive area that is off limits to nearly every other human activity. However, the wave park could coexist with a marine reserve or sanctuary. An exclusive use zone would be a first in the waters off the coast of the State of Oregon. The implications of this are quite significant: Once zoning begins, it will set a precedent for further zoning attempts for such uses as oil and mineral extraction; aquaculture; recreational zones; zoning for a particular fishery; and further wave energy developments. Regulators and ocean policy developers will have to consider the long-term implications of such an action as well as the potential cumulative effects of single use zones.

Questions Yet to be Answered

1. Placement of a wave park with structures in the water creates new navigational hazards and liability risks. How will exposure to these risks be reduced?
2. If mitigation for loss of fishing grounds is needed, how would mitigation be structured?
3. Will a wave energy park accommodate recreational fishing, commercial fishing, and boating within its boundaries?
4. If a wave park becomes a complete "no fishing" zone, will credit for this de facto marine reserve (sanctuary) be recognized by government agencies, and Non-Governmental Organizations (NGOs)?
5. Can adequate research be done to determine the effects of multiply buoys on the biological environment? OSU Marine Biologists have provided Appendix A for suggested areas of study to investigate the effects on the marine environment.
6. What benefits will come to the communities that are inshore of the wave energy parks? What are the costs to the communities that lay inshore of the sites?

Summary

In this paper, several opportunities and implications regarding ocean wave energy have been presented including cable protection strategies that minimize impacts to the fishing industry and research and development activities at Oregon State University. The conference presentation will include ongoing developments regarding the formation of a U.S. Wave Energy Research, Development and Demonstration Center in Oregon, as well as the developing, permitting and siting of commercial wave parks off the Oregon coast.

Appendix A

Wave Energy Park Environmental Monitoring Suggestions Under Development

Effects of Electromagnetic Fields:

- Sea bird attraction?
- Marine Mammal attraction, repulsion. Changes in whale migration pathways.
- Change in larval dispersion.
- Change in fish use of area, change in fish migration, change in fish reproductive success.
- Shark attraction.

Effects from construction/deployment/service of cables

- The most destructive aspect of laying natural gas lines is during the deployment of lines; the seafloor with its inhabitants is altered as the line is laid with large machinery. Similar effects could be expected with lying of electric cables if similar methods are used.
- Impact on invertebrates or seafloor structure from placement of anchors and power lines.
- Creation of a sediment plume and resulting impacts on fish/invertebrates.

Effects of the physical structure of the buoy field.

- Entanglement of marine mammals: whales, dolphins.
- Effects of using antifouling agents: introduction of toxics.
- Creation of a new community:
    - Does the new structure act as a filter for larval dispersal so that recruitment in surrounding areas is decreased?
    - Will the structure create a new habitat that will facilitate recruit and production of marine organisms?

Monitoring needs to be scale appropriate.

- Impacts from small scale may not be scaleable to large energy generation farms.
- Monitoring program needs to be adaptive in design to respond to evolving impacts.

Monitoring needs to compare manipulated and un-manipulated areas.