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Wave Energy

Amir Vosough
Department of Mechanics, Mahshahr Branch, Islamic Azad University, Mahshahr, Iran
vosoogh_amir@yahoo.com

Abstract– **Wave power is the transport of energy by ocean surface waves, and the capture of that energy to do useful work – for example, electricity generation, water desalination, or the pumping of water (into reservoirs). Machinery able to exploit wave power is generally known as a wave energy converter (WEC). Wave power is distinct from the diurnal flux of tidal power and the steady gyre of ocean currents. In this paper about the different parts of wave power like physical concept, wave power formula, wave energy, deep power characteristic and opportunities, modern technologies and its challenges and different kind of wave energy extractors have been discussed.**

Keywords– WEC, Flux, Wave Power and Challenges

I. INTRODUCTION

The first known patent to utilize energy from ocean waves dates back to 1799 and was filed in Paris by Girard and his son. An early application of wave power was devices constructed around 1910 by Bochaux-Praceique to light and power his house at Royan, near Bordeaux in France. It appears that this was the first Oscillating Water Column type of wave energy device [6]. From 1855 to 1973 there were already 340 patents filed in the UK alone. Modern scientific pursuit of wave energy was however pioneered by Yoshio Masuda's experiments in the 1940s. He has tested various concepts of wave energy devices at sea, with several hundred units used to power navigation lights. Among these was the concept of extracting power from the angular motion at the joints of an articulated raft, which was proposed in the 1950s by Masuda.

A renewed interest in wave energy was motivated by the oil crisis in 1973. A number of university researchers reexamined the potential of generating energy from ocean waves, among whom notably were Stephen Salter from the University of Edinburgh, Kjell Budal and Johannes Falnes from Norwegian Institute of Technology (now merged into Norwegian University of Science and Technology), Michael E. McCormick from U. S. Naval Academy, David Evans from Bristol University, Michael French from University of Lancaster, John Newman and Chiang C. Mei from MIT. In response to the Oil Crisis, a number of researchers reexamined the potential of generating energy from ocean waves, among whom is Professor Stephen Salter of the University of Edinburgh, Scotland.

His 1974 invention became known as Salter's Duck or Nodding Duck, although it was officially referred to as the Edinburgh Duck. In small scale controlled tests, the Duck's curved cam-like body can stop 90% of wave motion and can convert 90% of that to electricity giving 81% efficiency. In the 1980s, as the oil price went down, wave-energy funding was drastically reduced. Nevertheless, a few first-generation prototypes were tested at sea. More recently, following the issue of climate change, there is again a growing interest worldwide for renewable energy, including wave energy.

II. PHISICAL CONCEPT

Waves are generated by wind passing over the surface of the sea. As long as the waves propagate slower than the wind speed just above the waves, there is an energy transfer from the wind to the waves. Both air pressure differences between the upwind and the lee side of a wave crest, as well as friction on the water surface by the wind, making the water to go into the shear stress causes the growth of the waves [3]. Wave height is determined by wind speed, the duration of time the wind has been blowing, fetch (the distance over which the wind excites the waves) and by the depth and topography of the seafloor (which can focus or disperse the energy of the waves). A given wind speed has a matching practical limit over which time or distance will not produce larger waves. When this limit has been reached the sea is said to be "fully developed".

In general, larger waves are more powerful but wave power is also determined by wave speed, wavelength, and water density. Oscillatory motion is highest at the surface and diminishes exponentially with depth. However, for standing waves (clapotis) near a reflecting coast, wave energy is also present as pressure oscillations at great depth, producing microseisms [3]. These pressure fluctuations at greater depth are too small to be interesting from the point of view of wave power. The waves propagate on the ocean surface, and the wave energy is also transported horizontally with the group velocity. The mean transport rate of the wave energy through a vertical plane of unit width, parallel to a wave crest, is called the wave energy flux (or wave power, which must not be confused with the actual power generated by a wave power device).

III. WAVE POWER FORMULA

In deep water where the water depth is larger than half the wavelength, the wave energy flux is [6]:

$$P = \frac{\rho g^2}{64\pi} H_{m0}^2 T \approx \left(0.5 \frac{\mathrm{kW}}{\mathrm{m}^3 \cdot \mathrm{s}}\right) H_{m0}^2\, T, \qquad (1)$$

with P the wave energy flux per unit of wave-crest length, H_{m0} the significant wave height, T the wave period, ρ the water density and g the acceleration by gravity. The above formula states that wave power is proportional to the wave period and to the square of the wave height. When the significant wave height is given in meters, and the wave period in seconds, the result is the wave power in kilowatts (kW) per meter of wave front length [4].

Example: Consider moderate ocean swells, in deep water, a few kilometers off a coastline, with a wave height of 3 meters and a wave period of 8 seconds. Using the formula to solve for power, we get [6]:

$$P \approx 0.5 \frac{\mathrm{kW}}{\mathrm{m}^3 \cdot \mathrm{s}} (3 \cdot \mathrm{m})^2 (8 \cdot \mathrm{s}) \approx 36 \frac{\mathrm{kW}}{\mathrm{m}}, \quad (2)$$

meaning there are 36 kilowatts of power potential per meter of coastline. In major storms, the largest waves offshore are about 15 meters high and have a period of about 15 seconds. According to the above formula, such waves carry about 1.7 MW of power across each meter of wave front. An effective wave power device captures as much as possible of the wave energy flux. As a result the waves will be of lower height in the region behind the wave power device.

IV. WAVE ENERGY AND WAVE ENERGY FLUX

In a sea state, the average energy density per unit area of gravity waves on the water surface is proportional to the wave height squared, according to linear wave theory [3]:

$$E = \frac{1}{16} \rho g H_{m0}^2, \quad (3)$$

where E is the mean wave energy density per unit horizontal area (J/m^2), the sum of kinetic and potential energy density per unit horizontal area. The potential energy density is equal to the kinetic energy, both contributing half to the wave energy density E, as can be expected from the equipartition theorem. In ocean waves, surface tension effects are negligible for wavelengths above a few decimeters. As the waves propagate, their energy is transported. The energy transport velocity is the group velocity. As a result, the wave energy flux, through a vertical plane of unit width perpendicular to the wave propagation direction, is equal to:

$$P = E\, c_g, \quad (4)$$

with c_g the group velocity (m/s). Due to the dispersion relation for water waves under the action of gravity, the group velocity depends on the wavelength λ, or equivalently, on the wave period T. Further, the dispersion relation is a function of the water depth h. As a result, the group velocity behaves differently in the limits of deep and shallow water, and at intermediate depths.

V. DEEP WATER CHARACTERISTICS AND OPPERTUNITIES

Deep water corresponds with a water depth larger than half the wavelength, which is the common situation in the sea and ocean. In deep water, longer period waves propagate faster and transport their energy faster. The deep-water group velocity is half the phase velocity. In shallow water, for wavelengths larger than twenty times the water depth, as found quite often near the coast, the group velocity is equal to the phase velocity [6].

The regularity of deep-water ocean swells, where "easy-to-predict long-wavelength oscillations" are typically seen, offers the opportunity for the development of energy harvesting technologies that are potentially less subject to physical damage by near-shore cresting waves.

VI. MODERN TECHNOLGY

Wave power devices are generally categorized by the method used to capture the energy of the waves, by location and by the power take-off system. Method types are point absorber or buoy; surfacing following or attenuator oriented parallel to the direction of wave propagation; terminator, oriented perpendicular to the direction of wave propagation; oscillating water column; and overtopping. Locations are shoreline, near shore and offshore.

Types of power take-off include: hydraulic ram, elastomeric hose pump, pump-to-shore, hydroelectric turbine, air turbine [6], and linear electrical generator. Some of these designs incorporate parabolic reflectors as a means of increasing the wave energy at the point of capture. These capture systems use the rise and fall motion of waves to capture energy [6]. Once the wave energy is captured at a wave source, power must be carried to the point of use or to a connection to the electrical grid by transmission power cables.

A. Potential

The realistically usable worldwide resource has been estimated to be greater than 2 TW [6]. Locations with the most potential for wave power include the western seaboard of Europe, the northern coast of the UK, and the Pacific coastlines of North and South America, Southern Africa, Australia, and New Zealand. The north and south temperate zones have the best sites for capturing wave power. The prevailing westerlies in these zones blow strongest in winter. Waves are very predictable; waves that are caused by winds can be predicted five days in advance.

B. Challenges

There is a potential impact on the marine environment. Noise pollution, for example, could have negative impact if not monitored, although the noise and visible impact of each design varies greatly [5]. Other biophysical impacts (flora and fauna, sediment regimes and water column structure and flows) of scaling up the technology are being studied. In terms of socio-economic challenges, wave farms can result in the displacement of commercial and recreational fishermen from productive fishing grounds, can change the pattern of beach sand nourishment, and may represent hazards to safe navigation. Waves generate about 2,700 gigawatts of power. Of those 2,700 gigawatts, only about 500 gigawatts can be captured with the current technology.

VII. WAVE FARMS

The Aguçadoura Wave Farm was the world's first wave farm. It was located 5 km (3 mi) offshore near Póvoa de Varzim north of Oporto in Portugal. The farm was designed to use three Pelamis wave energy converters to convert the motion of the ocean surface waves into electricity, totaling to 2.25 MW in total installed capacity. The farm first generated electricity in July 2008 and was officially opened on the 23rd of September 2008, by the Portuguese Minister of Economy [6]. The wave farm was shut down two months after the official opening in November 2008 as a result of the financial collapse of Babcock & Brown due to the global economic crisis. The machines were off-site at this time due to technical problems, and although resolved have not returned to site and were subsequently scrapped in 2011 as the technology had moved on to the P2 variant as supplied to Eon and Scottish Power Renewables [6]. A second phase of the project planned to increase the installed capacity to 21MW using a further 25 Pelamis machines is in doubt following Babcock's financial collapse. Funding for a 3MW wave farm in Scotland was announced on 20 February 2007 by the Scottish Executive, at a cost of over 4 million pounds, as part of a £13 million funding package for marine power in Scotland. The first of 66 machines was launched in May 2010. Funding has also been announced for the development of a Wave hub off the north coast of Cornwall, England. The Wave hub will act as giant extension cable, allowing arrays of wave energy generating devices to be connected to the electricity grid. The Wave hub will initially allow 20MW of capacity to be connected, with potential expansion to 40MW. Four device manufacturers have so far expressed interest in connecting to the Wave hub [6].

The scientists have calculated that wave energy gathered at Wave Hub will be enough to power up to 7,500 households. Savings that the Cornwall wave power generator will bring are significant: about 300,000 tons of carbon dioxide in the next 25 years. A CETO wave farm off the coast of Western Australia has been operating to prove commercial viability and, after preliminary environmental approval, is poised for further development.

VIII. TYPES OF WAVE ENERGY EXTRACTORS

Wave power devices extract energy directly from the surface motion of ocean waves or from pressure fluctuations below the surface. Through time several concepts to extraction of energy from waves have been invented and developed. More than 100 concepts are globally in varying levels of development and several are in demonstration phases.

There are four overall types of wave energy extractors:

- Oscillating water column – These devices contain a chamber where the water level changes as waves go in and out. As the water level changes so does the pressure, which causes air to flow through a turbine.
- Attenuator or linear absorber – The linear absorber structure is oriented roughly parallel to the direction of wave propagation and is composed of multiple sections that rotate in pitch and yaw relative to each other.
- Overtopping terminator – A terminator is a device that reflects or absorbs all the energy in a wave. Water is forced through a turbine by the power of the wave.
- Point absorber – These devices capture energy from the "up and down" motion of the waves. They may be fully or partially submerged. They are small compared to a typical wavelength and can absorb energy from all directions.

Wave energy technologies are designed to extract energy from the energy contained in the movement of waves. Systems to convert wave energy into electricity can be located at deep water sites (offshore), at shallow water sites (near shore) or eventually built into the coast line (shoreline). They vary in size from very large systems installed on their own, to smaller ones grouped into farms or arrays.

A. Major Challenges for Wave Energy Devices

The single most important challenge for wave energy technology is to develop survivability in full scale ocean environments. This has to be possible at a reasonable cost of investment to indicate a future economy in the cost of energy production. For a wave energy device to survive in the chosen wave environment several issues have to be solved, including anchoring or position control to allow a stable grid connection, storm protection and in general a strength of construction to withstand the three dimensional forces of the ocean. Another challenge is to find funding for the needed large-scale demonstration projects. Favorable feed-in tariffs for wave energy that is fed into the transmission grid; values from 20-25 c€/kWh may be necessary in the demonstration phase and are provided in some countries, such as Ireland, Portugal, and the UK.

Other countries provide values from more than 9 c€/kWh, such as Germany, France, and Spain; the feed-in tariff concept is a form of revenue support, in order to enable renewable energy technologies to overcome the initial phase in that they cannot compete with traditional generation technologies. They consist of a premium paid by the grid operators in addition to the regular price per kWh of electricity produced. The cost of energy production during the lifetime of the installation is also a challenge. The device needs to have a mass production potential and a forecast of materials costs, installation and maintenance expenses. For now, a good projection will be sufficient to allow a project to go forward, but this projection has to include the cost of grid connection and bringing the electricity onshore.

B. The Short History of Wave Devices in Demonstration

One of the first shore-based, grid-connected wave power unit to be installed was an oscillating water column system built into the coastline of the Island of Islay in Scotland in 2000. The 500-kW device was developed by Wavegen in cooperation with Queen's University Belfast. In 2003, Wave Dragon installed the world's first floating grid-connected wave power unit. The 57-meter-wide prototype was an exact replica (at a scale of 1:4.5) of a 260-meter-wide 4-MW machine with a capacity of 20 kW. Because of its subscale nature, this unit was deployed in a protected bay in Nissum Bredning in Denmark. Experimental data from more than 20,000 hours of operation have been collected. In July 2004, Pelamis was the first company to deploy a full-scale grid-connected wave power unit, in open seas at the European Marine Energy Center (EMEC) in Orkney, Scotland. Based on successful testing of this 750-kW unit at EMEC, Pelamis announced the first commercial sale of three devices wave power plant in Portugal. The 2.25-MW pilot plant, the 30-MW plant was deployed off the coast of Portugal in 2008 but is no longer operating primaruly due to financial problems. An Oscillating Water Column (OWC) onshore device of 400 kW in Pico, Portugal operates from time to time. The first section out of ten of a 500 kW near shore device, Wave Star has been in operation since 2009 at Hanstholm in Denmark. It has an installed power of 110 kW. Demonstration projects are also ongoing and planned in Australia, Canada, China, Ireland, Japan, Portugal, Spain, the United Kingdom, Denmark, and the U.S.

IX. CONCLUSION

In this paper about the different parts of wave power like physical concept, wave power formula, wave energy, deep power characteristic and opportunities, modern technologies and its challenges and different kind of wave energy extractors has been discussed. Waves are generated by wind passing over the surface of the sea. As long as the waves propagate slower than the wind speed just above the waves, there is an energy transfer from the wind to the waves. Wave power devices are generally categorized by the method used to capture the energy of the waves, by location and by the power take-off system. The realistically usable worldwide resource has been estimated to be greater than 2 TW Locations with the most potential for wave power include the western seaboard of Europe, the northern coast of the UK, and the Pacific coastlines of North and South America, Southern Africa, Australia, and New Zealand. The single most important challenge for wave energy technology is to develop survivability in full scale ocean environments. This has to be possible at a reasonable cost of investment to indicate a future economy in the cost of energy production.

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