One Step towards Harnessing Wave Energy

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Ocean wave energy is captured directly from surface waves or from pressure fluctuations below the surface. Oscillating Water Columns (OWCs) is a type of wave energy converter that functions on the principle of a blowhole, designed to harness green energy from the ocean. India was a trailblazer and a prototype was built at Vizhinjam, a fishing harbour off the coast of Thiruvananthapuram, Kerala during the late 1980s. Among more than 1,000 patents for extracting energy from the ocean, the oscillating water column (OWC) device is the most commonly used in the world.

Rolling waves advance towards the rocky shore. The howling sound of sea entering the narrow subterranean cavern could be heard from underneath your feet. The sense of anticipation is written large on the gaping face of tourists. In a second, a fountain of water gushes spectacularly out of a hole on the ground rising as tall as thirty metres. This dazzling show occurs almost every couple of minutes, at a natural blowhole, an unusual geological formation, at Hummanaya, Sri Lanka. With every incoming wave, sea water enters the submerged cave and rushes along the subterranean cavern to come out as a dramatic fountain from a blowhole on the ground.

Breathtaking blowholes inspired scientists desperately looking for an alternative source of energy during the tumultuous times of oil crisis of the mid-1970s. Oscillating Water Columns (OWCs), a type of Wave Energy Converter (WEC) that functions on the principle of a blowhole, was designed to harness green energy from the ocean. India was a trailblazer and a prototype was built at Vizhinjam, a fishing harbour off the coast of Thiruvananthapuram, Kerala during the late 1980s. Indian Institute of Technology, Madras (IITM) and the National Institute of Ocean Technology (NIOT) pioneered the research. Although the power plant was rated 150 kW, only during the monsoon, i.e., June to September, it could reach anywhere near it. During the quieter December to March period, the actual output was just 25 kW. While two decades of its operation provided some insights to the researchers, the plant itself was decommissioned in 2011.

By the 2000s the OWC had become a forgotten chapter, and the associated research had come to almost standstill. Dr. Abdus Samad, a young faculty with a PhD from Inha University, the Republic of Korea and a post-doctoral stint at University of Aberdeen (UK) and Zi-Lift Ltd. (UK) designing novel downhole pumps, arrived at IIT-Madras. “One day, as I was walking around the labs on a quiet afternoon
after lunch I found an acrylic-made structure lying in our wave basin area in the Department of Ocean Engineering. I asked someone and came to know about the OWC research was done in India. I started studying about it, and found that the wave energy harvesting programme was launched by IITM and NIOT way back in the 1980s” recalls Dr. Samad.

Intrigued by the odd rusting contraptions gathering dust, he revisited the research that was earlier carried out at the IITM. He understood the performance of one of the key elements in the OWC system was the turbine, which was severely in need of performance enhancement design. Samad says, “The heart of the oscillating water column (OWC) system is a turbine, which gives very low power output because it has low efficiency and low operating range. Apparently, these weaknesses make the system performance poor”.

He found that the key to solving the problem is to make the turbine perform better. He approached Ministry of Earth Sciences (MoES) with a modest request of ₹10 lakh for the project to modify the design with numerical modelling. His subsequent discussion with NIOT (an institute under MoES) enlarged the scope, and they got a generous grant of ₹25 lakh. “I got a liberal project support from the Ministry because the country needed it, and my project scope got enlarged,” Samad says with pride.

Now Abdus Samad and Paresh Halder of Wave Energy and Fluids Engineering Laboratory of IITM and Dominique Thevenin Laboratory of Fluid Dynamics & Technical Flows, University of Magdeburg, Germany have come out with an improved design of a turbine for a higher operating range.

Wave energy

Stand on the edge of the beach, roaring waves gush towards and push you backwards. The moving water has lots of energy. The ripples caused on the surface of the ocean by the wind results in the sea waves. As the wind blows across the surface of the ocean, part of the energy is transferred through shear stresses to generate the waves, which then propagate to far off coasts. The wave height and wave period depend upon the wind speed, fetch (distance of water surface exposed to wind for making waves), and duration. The energy in the wave is proportional to the square of the wave height and wave speed. And it is quite a lot, if only we can harness a part of it.

Blowhole
Contrary to our intuition that water moves forward with each wave, like ripples in a pond, ocean waves are a form of surface waves, where the particles travel in a circular motion with very little forward motion. Oscillating water column (OWC) is a novel instrument to capture that energy; that is, the forward moving momentum of the waves and convert it into electricity.

**Oscillating Water Columns**

But what is OWC? In short, it is an artificial blowhole, using the periodic in-and-out motion of waves in a partially submerged column to force air to turn a turbine. Like a natural blowhole; the OWC has a partially submerged flat structure with an inlet below the waterline. The water inlet enters a chamber atop which a vertical column is placed. As a wave rolls in and out, the water level within the enclosure oscillates up and down. The oscillating water column acts like a giant piston acting on the air in the vertical column. Incoming wave makes water level

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**The Sun heats up Earth but not to the same extent everywhere.** The differential heating causes winds to blow. As these winds blow across oceans, they transfer some of their energy to water and create waves. The amount of energy transferred depends upon (a) the speed of the wind (b) the length of time for which it blows (c) the distance over which it blows (the ‘fetch’).
rise, the air flushes out forcing past a turbine placed at the top of the vertical column. The gushing air rotates the turbine generating electricity. While the wave recedes, as the water level drops, air is sucked on the reverse direction through the vertical column, once again making the turbine rotate, generating more electricity. (It must be mentioned here that the turbine used here is of a special type that keeps rotating in the same direction irrespective of the direction of air flow.) Thus the ‘oscillation of water column’ resulting from the crest and trough of the sea waves is exploited to produce electricity.

Unlike many other strategies for harnessing energy from the ocean, in OWC is often built near the shore that makes it easy for it to be linked with the power grid and maintenance. Further, as almost all the moving parts are housed outside of the water, a longer lifetime of the materials can be secured. “Among more than 1,000 patents for extracting energy from the ocean, the oscillating water column (OWC) device is the most commonly used in the world,” says Samad.

**History**

Thirty-four whistling buoys using the OWC principle was in operation on the coast of the USA as an audible warning device as far back as 1885. Instead of a turbine atop the vertical air column a whistle was placed, and the buoys, replacing the traditional bell buoys, made a warning sound every time air gushed out or was sucked
in. Probably the first real OWC device that generated electricity was constructed around 1910 at Royan, near Bordeaux in France. The device that had an output of 1 kW produced the electricity needed for lighting a mansion.

By then the OWC was routinely used in the field of navigation buoys to power navigation lights, although the output was small in the range of 70–500 W. The International Energy Agency (IEA), an intergovernmental organisation established under the Organisation for Economic Cooperation and Development (OECD) to find alternatives to oil and coal, took an interest in exploring ways of exploiting wave energy. Supported by the IEA, Japan Marine Science and Technology Centre (JAMSTEC), commissioned a prototype plant at Kaimei in the Sea of Japan. With partnership from UK, Canada, Ireland, and the USA, the 800-tonne 80-m long barge was moored off the coast of Yura, Tsuruoka City, Yamagata Prefecture. Nine generators, each having a nominal 125 kW rating, placed on the floating type power plant, were fuelled by the wave action that resulted in the internal water levels to rise and fall, forcing an alternating airflow that was used to drive air turbines.

With the oil crisis abetting by late 1980s, interest in developing wave power waned. But again, by 1990, with the realisation of the need for green and clean energy sources, the chase for alternative sources renewed. Japan, India, China, Norway, Portugal and Britain commenced experimenting with prototypes for exploitation of wave energy. A 500 kW, oscillating water column device came up at Islay Limpet, Scotland in 1991. Waveroller was installed in Finland in 1994. Powerbouy developed by the Ocean Power Technologies was commissioned in 1997 in the USA. Agucadoara Wave Farm, first ever, albeit short-lived, wave farm came up in Portugal in 2008. Mutriku Breakwater Wave Plant in Spain, SDE Sea Waves Power Plant by Israel came up in 2009 and 2011 respectively.

**Indian effort**

India was a trailblazer in harnessing ocean energy. With a long coastline of 7,000 kilometres it was estimated that it could be possible to generate about 40,000 MW. Mooted by the Indian Institute of Technology Madras in 1982, a 150-kW OWC prototype was established in 1991 as a National Test Facility to study the feasibility of harnessing wave energy. The initial efforts were much involved with drama; the first prototype wave power plant built during 1988 met with an accident during towing and seating. Undeterred, learning from the trail, the second was built and successfully installed during 1990.

Predictably the energy generated varied considerably with seasons. Wave energy research...
on optimum centre-to-centre spacing between the caissons, research on improving the pneumatic efficiency, techniques to reduce the wave force on the caisson, performance of the turbine, controlling corrosion, etc., was carried out successfully with this prototype. “Several turbines and generators were developed during the course and tested in the facility. The power generated at this facility from waves was used to power a 10,000 litres per day reverse osmosis plant for some time. This facility was decommissioned after demonstrating the technology successfully,” says Purnima Jalihal, Head, Energy and Fresh Water Division of NIOT, Chennai. Although the energy generation did not fructify, the technique led to the development of reverse osmosis-based desalination plant powered by wave energy which was fabricated and is being used in Kavaratti Island.

**Turbine**

With every incoming and outgoing wave, like the giant nostril, the vertical column sucks and blow air in and out. If a conventional turbine is placed atop the vertical column, to extract power, it too would be reversing direction in sync with the airflow. The generator or a dynamo attached to the turbine would also rotate one way and after a while another way. Hence the air turbine used in OWC is designed to rotate in the same direction, regardless of the direction of the airflow. The Wells turbine and impulse turbine are two such air turbines available and “NIOT is currently developing bi-directional flow impulse turbines for their simplicity and ruggedness, and twin unidirectional flow impulse turbine topology for its potential for very high efficiency,” says Purnima.

The earlier Vizhinjam experiment provided crucial insights into the Wells turbine. Both Wells turbine and impulse turbine operate in the reversing airflow generated by OWC. “As incident wave height changes continuously, the airflow induced by OWC changes constantly in magnitude. Hence the turbine chosen should operate efficiently over a wide range of flow rate. Impulse turbines are marginally more efficient than Wells turbines at respective best operating points, but also remain effective over a much wider range of airflow rates,” says Purnima. NIOT is trying to develop various
wave energy capture devices using impulse turbine.

**Research**

Optimising the aerofoil shape of the turbine blade, results in increasing the efficiency of the turbine and power output. Routinely blade shape modifications are made in the gas turbine, steam turbine and hydro turbine to enhance the performance; air turbine for OWC is a relatively newer development and attempts to improve its results by modifying blade shape is limited.

Samad and his team created the Wave Energy and Fluids Engineering Laboratory (WEFEL) to test various turbine designs used for extracting wave energy. “The lab was started from a dump-yard. From cleaning, flooring, lighting, painting, connecting water, the internet, installing doors, and windows, cutting drain to avoid seasonal rain congestion, constructing a road to the lab, installing equipment,” Samad says was done by him and his staff. It took five years to set the lab and facilities, and today the state-of-the-art lab contains reciprocating airflow test rig, which mimics the wave in the ocean, data acquisition system and all the performance measuring instruments in which fifteen researchers are working.

Samad says, “The lab is trying to improve the performance of the whole OWC system. We have code for optimisation and computational fluid dynamics (CFD), and we model many alternative designs to find an optimal design. This needs immense knowledge of mathematics, fluid dynamics and mechanical engineering. We also have electrical engineers to solve the problem of stable
frequency.” The recent paper done in collaboration with the researcher at the University of Magdeburg is an effort to optimise the sweep angles of a Wells turbine blade and to reduce the separation zone. Their numerical results, published in *Renewable Energy*, Vol 106, June 2017 provide design optimisation to widen the operating range of a Wells turbine through blade shape modification. Such studies take us one step closer to realising operational OWC generators producing power. Samad says, “Lot more needs to be done. We need to test the design in the field, and laboratory studies alone will not do. Floating OWC platform of NIOT is being used to test our results on the ground and scientists from NIOT are collaborating in our work.”

**Way forward**

World’s oceans, one estimate says, can provide 2 trillion watts (W) of electricity. Purnima says “although proper resource assessment at specific sites in India is required to assess the true potential, as per the standard world map, Indian potential is around 14 kW per m on an average.” With about 7,500 km shoreline, even with modest 10% utilisation, the energy generated could be anywhere between 3,750-7,500 MW. “The east and west coast both are having a potential to harvest energy. The islands such as the Andaman Island also have some potential,” opines Dr. Samad. NIOT, under the Ministry of Earth Sciences, has embarked upon developing “floating wave energy backward bent ducted buoy for powering small loads, especially for islands and remote locations which are ready for scaling up. Further, NIOT is also developing wave powered navigational buoy which will undergo extensive sea trials very soon,” says Purnima.

Although for centuries technologies have existed for extracting wave power, very little have been done for making them efficient and commercially viable. The looming threat of global warming and the urgent need to shift from fossil fuel have compelled many countries to turn to wave power seriously. One of the major hurdles is the initial set-up cost. Compared to other power plants, the maintenance cost of OWC plants is much lower, but site-specific technological challenges like erosion of coastal line and so on need to be addressed adequately.

There are some factors that go in support of extracting wave energy. Unlike wind and solar power, we can extract energy from the ocean waves around the clock. Power from the wind is proportional to the cube of its speed whereas it is square of wave height in case of wave energy. This implies, per unit time, the average power production would be higher in the case of wave power than wind. Wave energy is a renewable and a sustainable form of energy that can perhaps contribute significantly to the building up of low-carbon economies.

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