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# Ocean energy technology development and demonstration activities by NIOT

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**ABSTRACT**

Today, the world faces several climate change-related issues due to pollution. The globe is seeing several alternate sources of renewable energy. Also, there is an acute energy crisis due to fast-depleting fossil fuel reserves on the earth, and there will be a time, when the known reserves will become extinct, or extraction from these reserves will become highly costly and technologically challenging, not forgetting the fact that this exploitation has led to adverse effects on the earth's climate. While solar, wind, biomass, and other forms are already being tapped globally, renewable energy resources that can be harnessed from the vast oceans, have now become a focus of the scientific community worldwide. The oceans offer huge spaces where new technologies can be tried and tested without affecting human settlement or the environment. Many countries have already started working towards this. In India, this development is led by the National Institute of Ocean Technology (NIOT). Extensive efforts are being made at this institute to develop technologies related to the energy extraction from ocean waves, based on the oscillating water column principle, from ocean currents using principles of hydrokinetics, and from ocean thermal gradient along the sea depth using a rankine cycle. The floating wave energy devices like backwards bent ducted buoy and wave-powered navigational buoy, cross flow hydro kinetic turbine and Open cycle ocean thermal energy conversion (OTEC), are a few of the technologies that have been developed and demonstrated. The development consists of numerical analyses, laboratory studies and open sea trials. This paper briefly discusses these developmental activities and the status of the development of ocean energy by NIOT. It also discusses all these indigenously developed ocean energy conversion systems, their performance during the testing phase, and their challenges and opportunities in India.

**Keywords:** Ocean energy, Wave energy, Oscillating Water Column (OWC), Hydro kinetic energy, Ocean Thermal Energy Conversion (OTEC), Renewable energy

## INTRODUCTION

India has a very long coastline of about 7500 km (Dimri et al., 2023) and has very high tidal variation in specific sites (Raju and Ravindran, 1997). As a tropical country, India also possesses vast potential for OTEC resources. The ocean has approximately 8,000-80,000 TW/year of wave energy around the globe (Gunn and Stock-Williams, 2012). 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 (Folley and Whittaker, 2009). India is estimated to have a potential of 41GW of wave energy as per a study by the Indian Renewable Energy Development Agency Limited (IREDA) (Indian Renewable Energy, 2014). The average wave energy potential is estimated at 5-15 kW per meter of coastline. The Ministry of New and Renewable Energy (MNRE), assessed the potential of tidal energy in the country. The study indicated an estimated potential of about 8000 MW, with 7000 MW in the Gulf of Khambhat, 1200 MW in the Gulf of Kutch in Gujarat, and 100 MW in the Gangetic deltas in Sunder bans in West Bengal (Sannasiraj and Sundar, 2016). Based on the available literature, overall net power available from OTEC is around 9 to 10 TW (Ascari, 2012). A minimum temperature difference of $20^{o}$C between the surface and deep-sea water is necessary for establishing an OTEC plant (Nihous, 2007). Water drawn from depths of 1000 m, will provide the above-mentioned temperature difference. Such conditions are more eminent in the country's Exclusive Economic Zone (EEZ). Theoretical estimates of the OTEC resource in India's EEZ, is around 180000 MW (Indian Renewable Energy, 2014). However, this is still under study and has to be asserted.

Further, wave-capturing devices can be installed near shore or offshore (Isaacs and Seymour, 1973; IEC, 2015) . Three fundamental methods for harnessing wave energy are, wave profile devices, oscillating water columns, and wave capture devices. Further, there are two main forms of practical tidal energy harvesting methodologies, tidal stream turbines and tidal barrages (Isaacs and Seymour, 1973). Currently, countries such as the United Kingdom, France, Canada, and China are leading in the development and deployment of tidal energy projects. The UK, in particular, has been a pioneer in this field, with the world's first tidal energy plant being established in 2016 in Scotland. With the growing interest in OTEC technology's potential to provide clean, reliable and sustainable energy, countries like Japan, India and United States are leading in OTEC research and development. OTEC works by harnessing the difference in temperature between warm surface waters and cold deep ocean waters to generate power through a heat engine (Jia et al., 2018). While OTEC is still in the early stages of development and faces challenges such as high capital costs, it has the potential to become a significant source of renewable energy for coastal communities around the world since it is a base-load source of power. With continued research and investment, we may see OTEC playing a vital role in our transition to a more sustainable future. There are three types of electricity conversion systems under OTEC: closed-cycle, open-cycle, and hybrid cycle.

A detailed study on the concept of an OTEC plant was initiated in India in 1980, and NIOT proposed to establish a 1 MW plant in 1997. In 2001, a floating closed cycle OTEC plant was constructed by NIOT, which was 40 km off the mainland in Tuticorin. Due to challenges in installation from lack of marine infrastructure for deep waters, the project could not be completed and onshore low temperature thermal desalination (LTTD) was instead attempted where cold water from comparatively shallow water depths sufficed. Successful desalinated water using ocean thermal gradient was generated at Kavaratti, Minicoy, Agatti, Kalpeni, Kadamath, Amini and Chetlat Lakshadweep Island. All these plants are continuously supplying potable water to the islanders. Various indigenous technologies developed by NIOT are discussed below as shown in Figure 1.

NIOT has been spearheading wave energy development in India. There have been three distinct developments by NIOT (a) a wave energy plant at Vizhinjam (a project started by the Indian Institute of Technology Madras and later taken over by NIOT), (b) a floating wave energy device backward bent ducted buoy to power small loads, and (c) wave-powered navigational buoy. These three developments employ oscillating water column (OWC) technique for harnessing energy in waves. All the three developments have led to successful demonstration of the wave energy conversion. NIOT has thus developed the know-how for taking wave energy conversion technology to a larger scale. This institute has been developing and demonstrating various techniques to efficiently utilize the abundant ocean waves and ocean temperature gradient available to generate energy. The progress in the development and demonstration of these techniques is shown in Figure 2. This paper discusses about the development of the power module for different energy generation methods such as wave, tidal, and OTEC energy.

## METHODOLOGY

The development of ocean energy devices that took place after 2011, their operating principle, details of power module and real-time performance assessment during open sea trials are discussed here. The flow chart depicting the power module assessment for different technologies is shown in Figure 3.

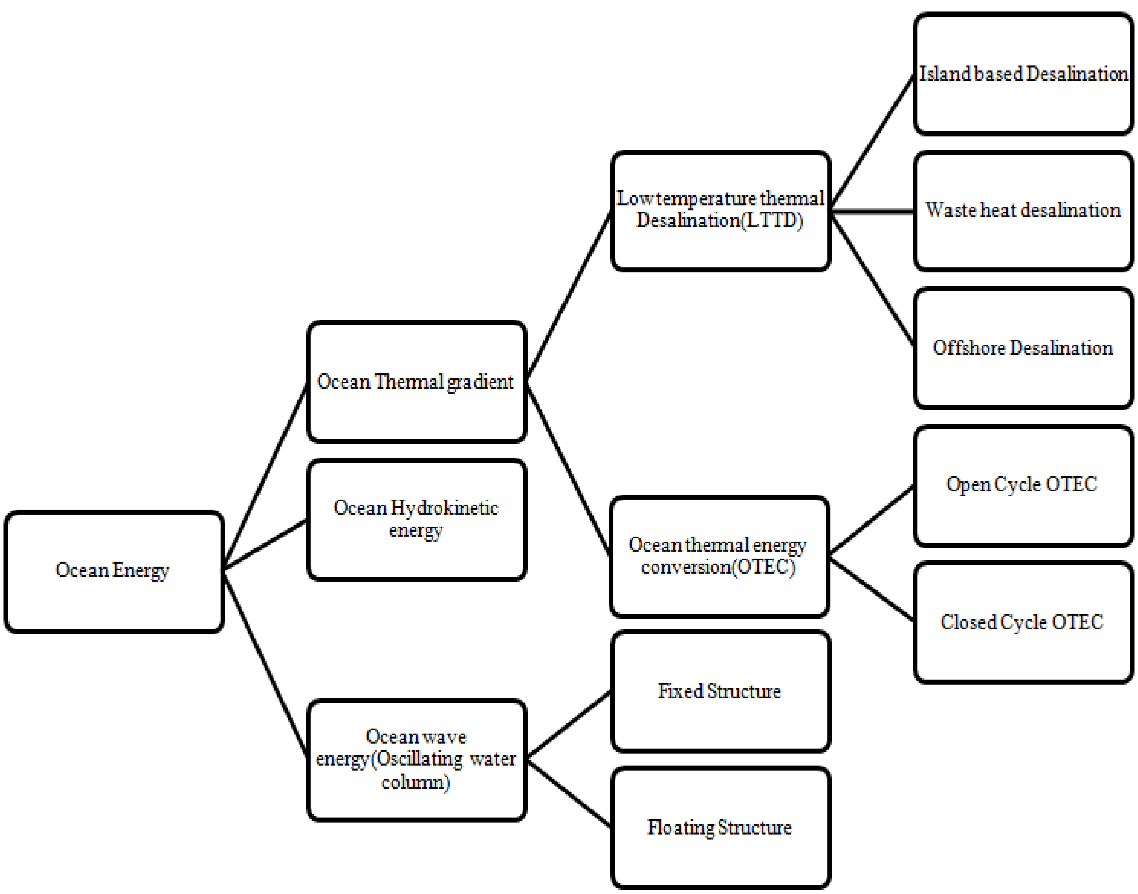


**Figure 1.** Various technologies used for harnessing ocean energy: Indian scenario.

**Wave Energy Turbine**

The BBDB is a floating type wave energy device. It consists of an interconnected vertical and horizontal duct typically 'L' shaped, which acts as the oscillating water column, sufficient buoyancy, mooring and a power module consisting of a turbine and a generator. The horizontal duct which is oriented away from the wave direction, allows enhanced movement of water in and out of chamber. This makes the water level in the vertical duct oscillate. The air above the water's surface thus is pushed out and sucked in alternately. This air drives the turbine. The BBDB fitted with a single unidirectional turbine, coupled with permanent magnet direct current (PMDC) generator, was tested in the open sea off the Chennai coast near Kamarajar port Limited (KPL). NIOT successfully carried out open sea trials on BBDB during 2011- 2015.


**Figure 2.** Progress in demonstration of harnessing ocean energy

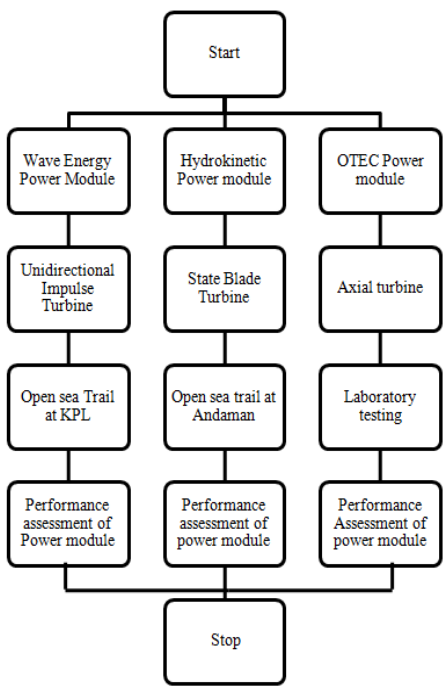


**Figure 3.** Power module assessment

Based on the results and understandings from this experience, a product was designed and developed that is called wave powered navigational buoy. The OWC diameter decides the discharge and pressure across the turbine and hence plays a critical role in the overall sizing of this buoy. The numerical study was carried out in RANS based CFD commercial code STAR-CCM+ (Vishwanath, 2019). Physical model experiments were also conducted on scaled down physical model of this buoy in the wave flume for the various wave conditions. The fabricated navigational buoy and the deployment location are shown in Figure 4**.** The wave-powered navigational buoy has a floating buoy in a partially submerged condition. The chamber is open to the sea below the water level so that when the wave passes over it, the water level rises, and the air gets pressurized. This pressure forces the air through an aperture at the top of the chamber and drives the turbine which is connected to the electric generator for the generation of electricity. The chamber can be shaped such that its cross-sectional area reduces towards the top, called the dome, creating a high-speed airflow required for driving the turbine from the slow-moving surface of the water. To keep the buoy in an upright position, a counterweight is attached at the bottom of the spar.

An OWC wave-powered navigational buoy using the same power module, was successfully sized and for optimized performance. The buoy was fabricated in-house, and the first prototype was tested off Ennore, Chennai, in 2018 near KPL (Pattanaik, 2018). The power module plays a significant role in the optimized generation of electricity. The wave energy power module works with the unidirectional impulse (UDI) turbine. Table 1 shows the details of the turbine developed for the wave powered navigational buoy. Once the assembly was completed, it was taken for open sea trial at KPL. Then, the performance assessment of the power module was studied. These wave buoys are solar powered and prone to vandalism. India has several ports and harbors that use navigational buoys. They can be substituted by a wave powered navigational buoy. Also, India has a well-connected network of metocean data buoys, which can be replaced with these wave powered navigational buoy as they can generate self-sustained small power demand of buoys.

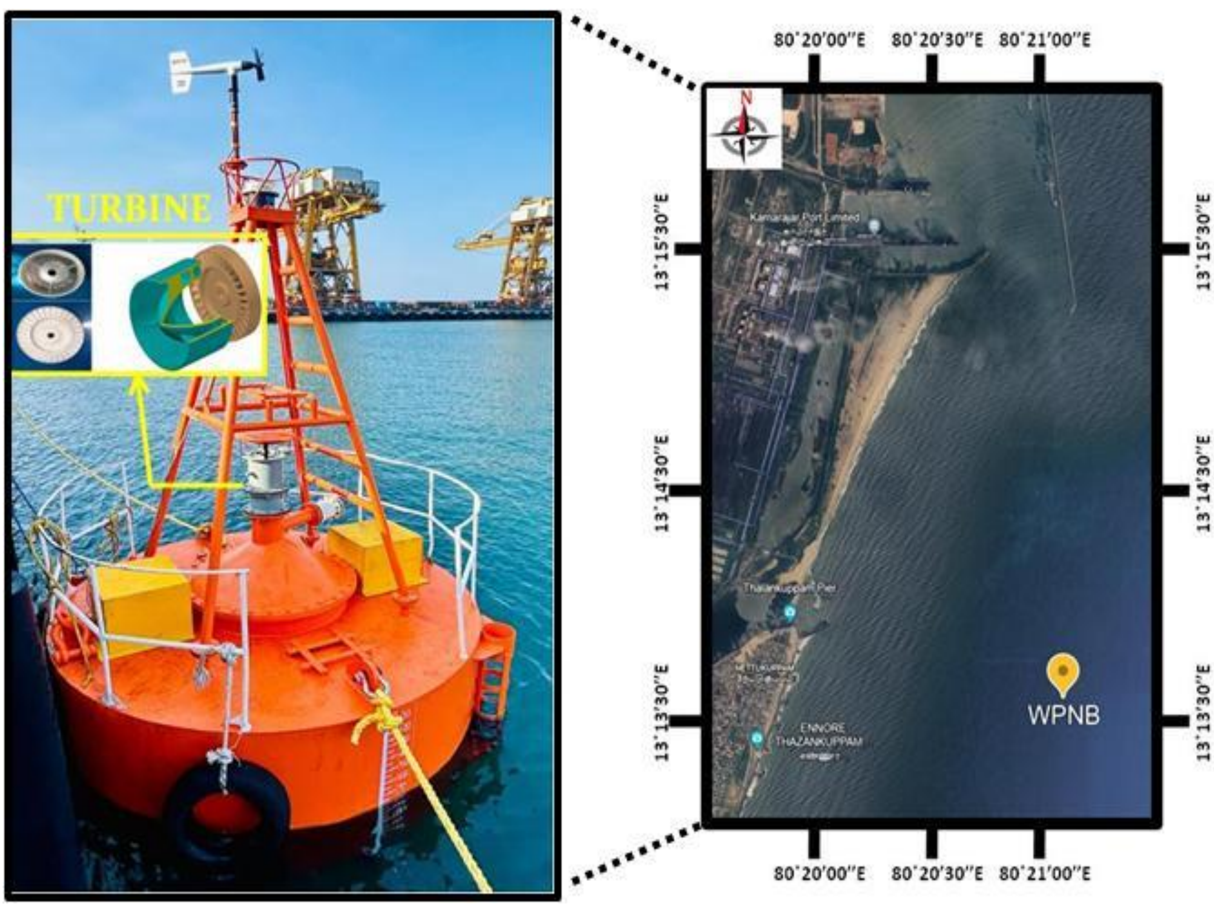


**Figure 4.** Wave Powered Navigational Buoy (Left) with deployed location (Right)

## HYDROKINETIC TURBINE

The turbine design includes design and optimization using computational fluid dynamics (CFD) principles. Several turbines were tested in the towing tank facility at IIT Madras and a seawater channel in North Chennai. Following extensive studies, NIOT carried out successful sea trials in the Andaman and Nicobar Islands. The turbine configuration finally chosen for the hydrokinetic turbine deployment was a straight-bladed cross flow turbine, and after complete assembly, it was taken to Andaman for an open sea trial. South Andaman was chosen for the mentioned study, and Macpherson Strait region was selected for desire after measuring the depth profile and current profiles using ADCP. The location had a depth of 20 m and current speed of 1m/s to 1.8m/s. The platform was fabricated at Port Blair and towed to the desired location through tug boats which was approximately 48 km. This region was under Mahatma Gandhi National Park, so special clearance had to be obtained from the forest officials to carry out the study. After successful demonstration, studies on the power module assessment were carried out. Figure 5 shows the demonstration of the hydro kinetic (HK) turbine at Andaman and the demonstration location. In Andaman, there are several remote places where renewable sources of energy such as solar and wind cannot be used; however tidal streams are available. This technology can be used as an alternative to cater to the small power requirement of water remote places in Andaman. Table 2 describes the features of the hydro kinetic turbine.

**Table 1**. Turbine of wave powered navigational buoy (WPNB)

| Particulars | |
|---|---|
| Medium | Air |
| Design for air | 0.14 $m^3$/hr |
| Diameter of turbine | 196 mm |
| No. of stator blades | 26 |
| No. of rotor blades | 30 |
| Chord length | 34 mm |
| Material | Polycarbonate |
| Type of fabrication | 3D printing |
| Type of generator | PMDC |
| Power module output | 48V/1500 rpm |

**Table 2.** Detailed features of hydrokinetic turbine

| Particulars | |
|---|---|
| Medium | Sea water stream |
| Design for water speed | 1.2 m/s |
| Diameter of turbine | 0.8 m |
| Number of blades | 3 |
| Length of turbine | 1 m |
| Blade material | FRP with steel reinforcement |
| Type of generator | Permanent magnet alternator |
| Power module output | 60V/750 rpm |

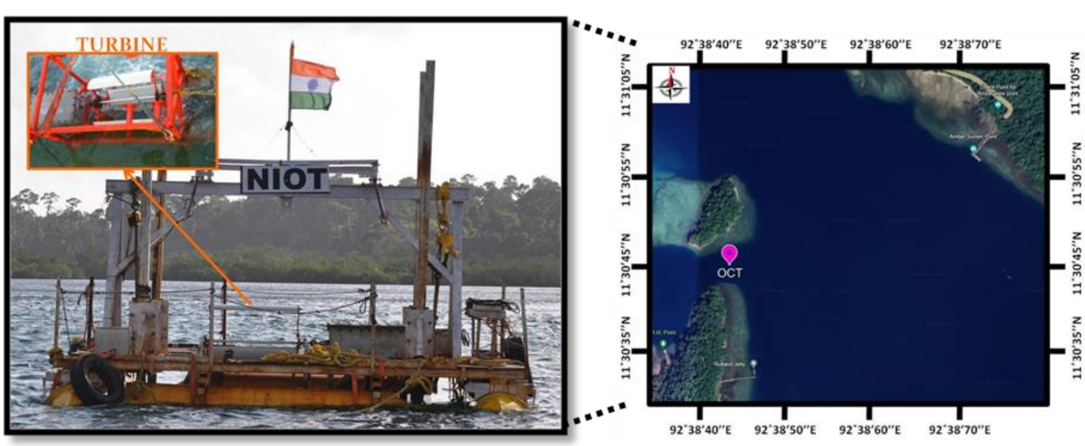


**Figure 5.** Demonstration of ocean current energy at Andaman (Left) with deployed location (Right)

## LABORATORY SCALE OTEC OPEN CYCLE POWER MODULE

Open Cycle Ocean Thermal Energy Conversion (OC-OTEC) and Low-Temperature Thermal Desalination (LTTD) processes, utilize the temperature difference between warm surface and cold deep ocean water to generate electricity and fresh water, respectively. The warm water is supplied to a flash chamber using a warm water pump where it gets vaporized, travels through a duct, expands in a low-pressure turbo-generator to generate electricity, and condenses in a condenser using cold water. A vacuum pump maintains the OC-OTEC system at low pressure. In the lab setup, temperature of warm water is maintained with the help of a heater, and cold-water temperature is maintained using a chiller. The experiment is run for a maximum of a few minutes with full warm and cold-water flow. The test facility plant schematic is shown in Figure 6.

The axial flow turbine was developed in house, its stator and rotor were fabricated using the selective laser sintering technique of rapid prototyping. These studies are useful for understanding process parameters for the OC-OTEC- based desalination plant and for setting up large-scale OTEC and self-sustained OTEC-based desalination plants in India. This laboratory facility has been useful for studying the cycle and optimizing the plant operation. NIOT is setting up an OC-OTEC plant in Kavaratti, Lakshadweep, which will have a desalination capacity of 1 lakh litres per day. As a tropical country, India possesses a huge potential for ocean thermal energy conversion (OTEC) resources. With the sufficient availability of ocean thermal gradients in India and its islands, generating electricity from OTEC as a renewable energy source is possible.

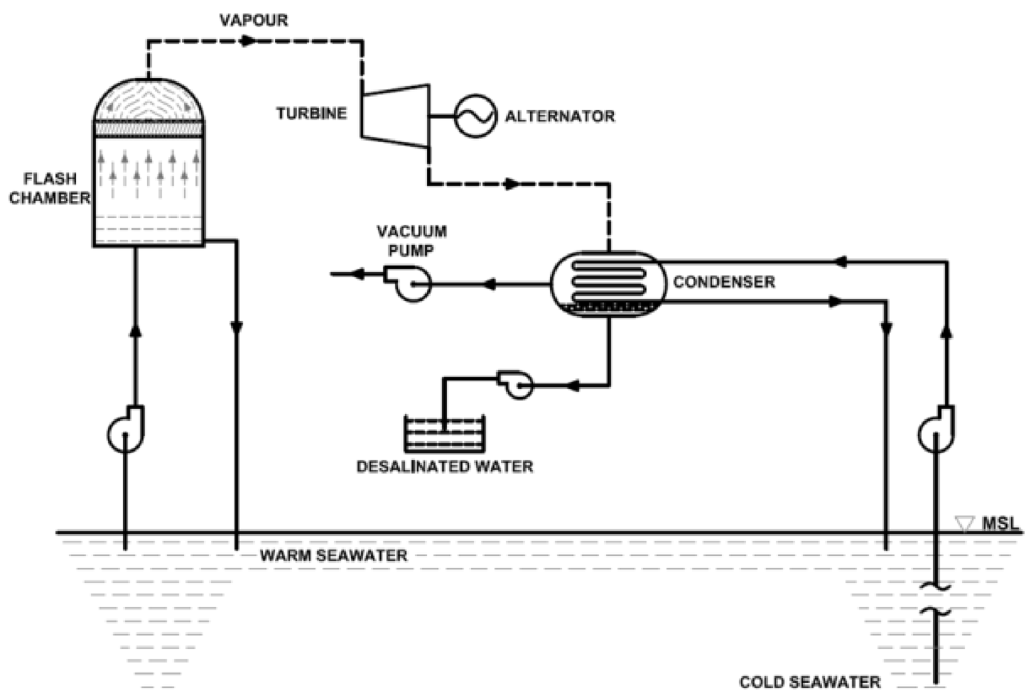


**Figure 6.** Schematic of open cycle - Ocean Thermal Energy Conversion plant

**Table 3.** Detailed feature of open cycle- Ocean Thermal Energy Conversion turbine

| Particulars | |
|---|---|
| Medium | Low-pressure steam |
| Diameter of turbine | 0.268 m |
| No. of stator blades | 35 |
| No. of rotor blades | 70 |
| Material | Aluminum alloy |
| Type of generator | BLDC |
| Power module output | 60V/20000 rpm |

In contrast to other renewable energy sources such as wind and solar, OTEC is a reliable source of renewable energy, maintaining a 90% load factor. Table 3 shows the details of the turbine developed for in-house OC-OTEC facility. Figure 7 shows the layout of the OC-OTEC facility.

## RESULTS OF DEVELOPED OCEAN ENERGY DEVICES

The results of experiments on open sea trials and lab testing of wave energy, hydrokinetic energy and OTEC power module are discussed here. It can be observed from Figure 8 that the instantaneous power developed by the UDI turbine reaches a maximum of 140W. The power generation is random as waves are random in nature. The waves are generally semi-directional and vary from time to time, so depending on the wave height and the period, the power generated is not uniform. The tidal current is generally a semidiurnal tide and changes with the direction of flow, but the turbine will rotate in one direction and generate power. It can be observed from Figure 9 that power developed by the current turbine reaches a maximum of 200 W.

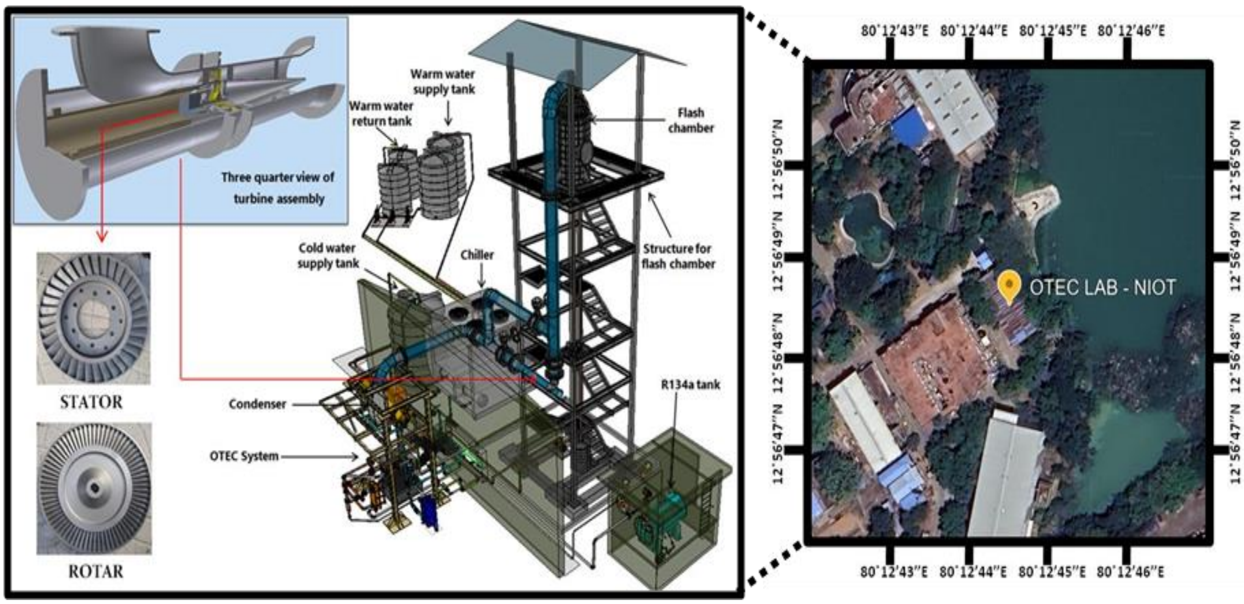


**Figure 7.** Location of open cycle - Ocean Thermal Energy Conversion lab setup at NIOT

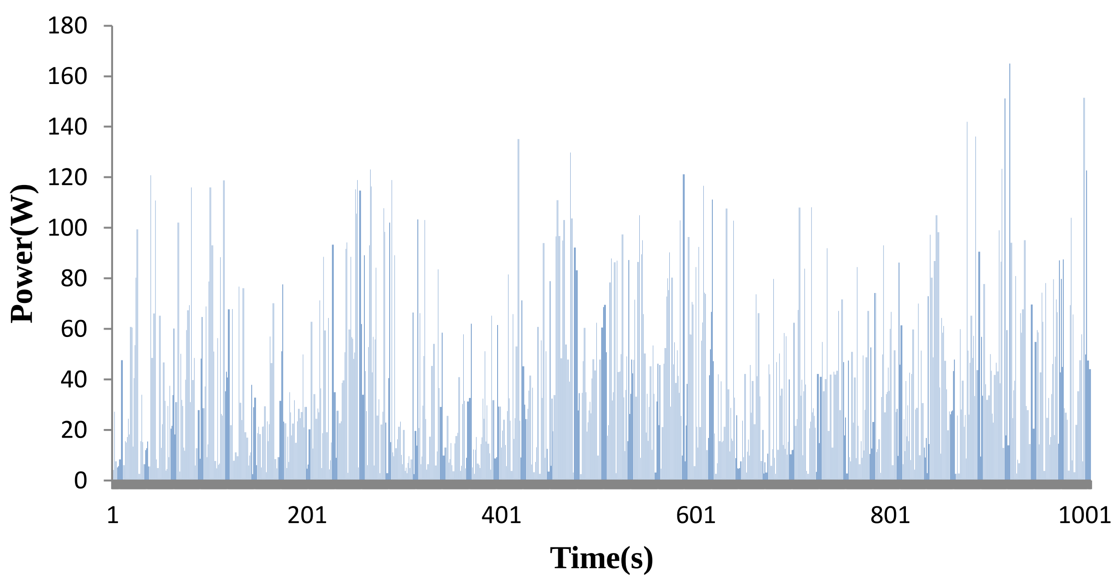


**Figure 8.** Unidirectional impulse turbine of wave energy power module

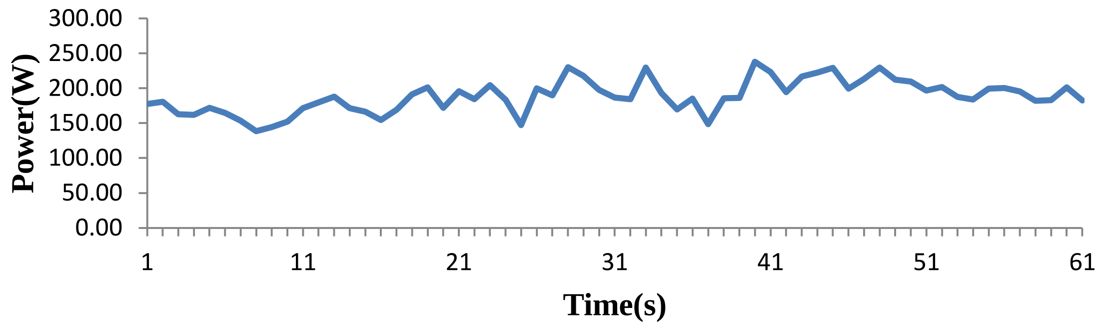


**Figure 9.** Current turbine power module

It is observed from Figure 10 that power developed by the OC-OTEC power module reaches a maximum of around 1400 W, and an average freshwater flow (MFW) of 0.056 kg/s is obtained. Figure 10 shows electric power generation in the primary axis and freshwater generation MFW in the secondary axis. The power generated over the period of time is steady and constant. The OTEC is an alternative source of ocean renewable energy forms that can generate electricity in remote islands for the nation.

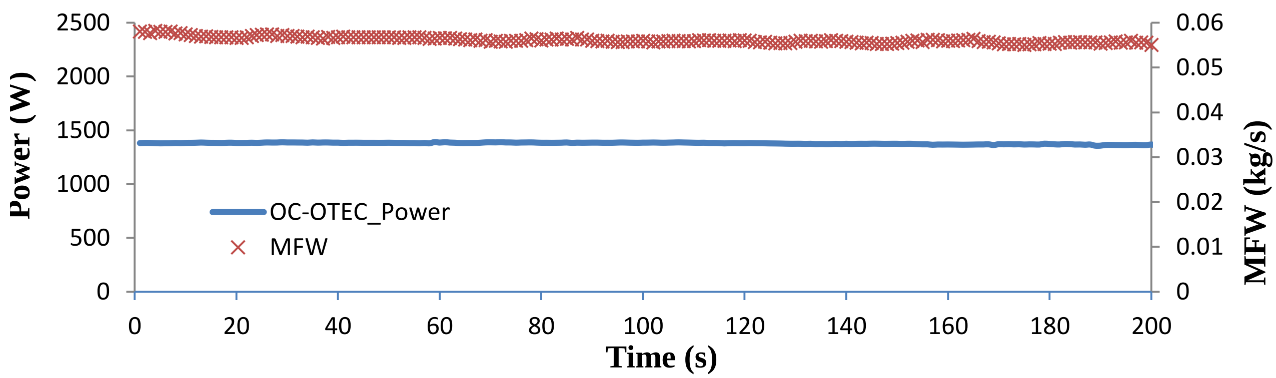


**Figure 10.** Open cycle Ocean Thermal Energy Conversion power module

## CONCLUSIONS

The development and demonstration activities related to ocean energy technology by NIOT, are focused on exploring the potential of renewable energy resources that can be harnessed from the vast oceans. With the acute energy crisis due to fast-depleting fossil fuel reserves and the adverse effects of fossil fuel exploitation on the earth's climate, ocean energy offers a promising solution. NIOT is working to develop technologies related to energy extraction from ocean waves, ocean currents, and ocean thermal gradient. There are several possibilities for generating electricity from OTEC as a renewable energy resource in India, which has a tropical climate and sufficient availability of ocean thermal gradients. While there are still challenges and opportunities related to ocean energy development in India, NIOT's efforts in this area are promising.

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**Author Credit Statement**

Biren Pattanaik: Data compilation, planning and manuscript preparation. Anulekha Majumdar: formal analysis and mapping. Prasad Dudhgaonkar: Planning and interpretation to strengthen the manuscript. Purnima Jalihal: critical feedback to strengthen the manuscript.

**Data Availability**

Data is based on internal study. It may be made available on reasonable request.

**Compliance With Ethical Standards**

All the authors have read the manuscript thoroughly and confirm that it has neither been submitted to any other journal and nor been considered for publication. All authors have been actively involved in substantive work leading to the manuscript and will hold themselves jointly and individually responsible for its content. Authors adhere to copyright norms.

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