PAPER • **OPEN ACCESS**

A Review on the Energy prospects of Indian Remote Islands and Preliminary assessment of Marine Current Energy Potential

To cite this article: P. Vyshnavi *et al* 2020 *J. Phys.: Conf. Ser.* **1716** 012007

A Review on the Energy prospects of Indian Remote Islands and Preliminary assessment of Marine Current Energy Potential

P. Vyshnavi[1], A. Samad[2], N. Venkatesan*[3], E.J. Avital[4]

[1]Department of Civil Engineering, KCG College of Technology, India,
[2]Department of Ocean Engineering, IIT Madras, India,
[3]School of Electrical Engineering, VIT, Chennai, India,
[4]Queen Mary University, London, UK,
Corresponding Author: nithya.v@vit.ac.in

Abstract. The islands in the Indian Ocean as other remote islands are often challenged to meet their energy needs, and constantly getting electricity from the mainland is expensive. In this article, the present scenario and future prospects of the energy sources for all the Indian islands are discussed. Data collected from different buoys of INCOIS are analysed, and a location near Minicoy has been chosen for further study. This paper also provides the preliminary analysis of marine current energy feasibility in that location.

1. Introduction

Many countries worldwide have remote islands where the energy supply is of acute importance as part of a sustainable development policy. India is of no exception. India is the seventh largest country in the world in terms of area, and the coastal line along the Indian peninsula stretches for about 7,517 kilometres (km). The islands near the west coast of India come under the Union Territory (UT) of Lakshadweep, which is at a distance of 200 km from the Indian mainland, and has a total population of around 65,000 [1]. This UT in the Arabian Sea consists of 36 islands, out of which only some are inhabited [2]. The UT of Andaman and Nicobar Islands, located to the east of India, comprises of 572 islands with a large number of islets, reefs and isolated rocks. These islands are at a distance of 1,200 km from the east coast of India, spread in the Bay of Bengal.

As these islands are isolated, grid-connected power transfer is not possible, and current energy production depends on fossil fuels shipped from the mainland. The burning of fossil fuels produces harmful gases like CO_2, CO, NOx, SO_2, etc., which have adverse effects on the human health. Furthermore, a major concern is to preserve the beautiful heritage of the islands while generating power. Hence, alternative sources of energy should be futuristic and sustainable for these types of islands. This issue is faced by other remote islands worldwide. In this study we seek a feasible approach to assess marine current energy power supply for an island.

The main objectives of this study are to:

a. Provide an update on generic ocean energy systems.

b. Assess the general ocean power systems suitable for remote islands.

c. Provide a detailed case study on a group of remote Indian islands.

1.1 Categories of Ocean Energy

The potential of solar and wind renewable energy is being widely explored and implemented in various parts of India. The energy potential of the seas and oceans are also huge in India as the country has a long coastline with several estuaries and gulfs where electric power generation is feasible. Many technologies to produce wave (~40,000 MW), tidal (~9000 MW) and thermal (~180,000 MW) energy are currently being developed and experimented throughout the world [3]. These systems are still in their early stages, but they may help reduce CO2 emission and facilitate to meet present and future energy demands, especially of the remote Indian islands and other worldwide.

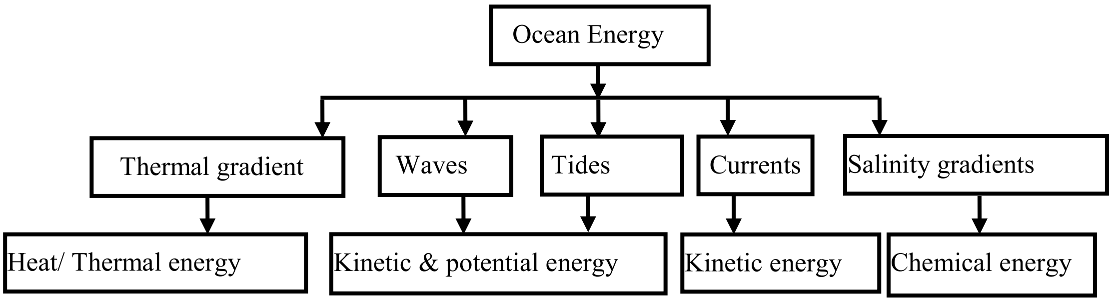


Figure 1. Classification of ocean energy.

Ocean energy or marine energy can be tapped in different ways as shown in the diagram of figure.1. The Ocean Thermal Energy Conversion (OTEC) system uses the temperature difference generally greater than 20˚C between the upper surface and the lower surface of seawater. The energy generated using the difference in salt content between two fluids, say freshwater and ocean water is known as salinity gradient energy. This energy gradient is then converted into electricity through heat exchangers and turbines [3]. In a wave energy harvesting system, the surface motion of ocean waves or pressure fluctuations below the surface of the water enables the device to extract energy [4]. Another phenomenon that occurs in the ocean is tides caused by the gravitational pull of the moon, the sun, and the earth. The gravitational force of the moon, due to it being closer to the earth, is 2.2 times larger than that of the sun [5]. Tidal power can be tapped by building tidal barrages using tidal stream turbines or using hybrid applications [6]. Tide generated currents are prominent near shores, bays, and estuaries along the coast, and is known as tidal currents. Oceanic currents generated by tides, salinity, wind or temperature cause the movement of water from one place to another [7].

2. Methodology

2.1 Ocean Energy for Indian Islands

Some of the major problems while generating electricity with the existing systems in the islands are high cost, low power production, high maintenance, pollution, etc. So there is an imminent need for an alternative system which overcomes all these issues besides serving the power needs. A thorough study of the newly proposed energy systems needs to be carried out before installing them to avoid a risk of failure, unnecessary costs, and also to save time. Here, a comparative study of the different ocean energy systems is made from various literatures as shown in table 1.

Table 1. Comparison of the various ocean energy systems.

Impacts	OTEC	Wave energy system	Osmotic power	Tidal or marine current turbine

Challenges	It needs large water ducts and should be securely connected, which is a challenge [3]	They may have potential navigational hazards to shipping and hence prone to the risk of collision [9].	It involves the construction of large plants which is difficult [10].	There is no such difficulties.
Operation issues	The plant needs to be aided with the large-scale pipes. Corrosion and biofouling of the pipes, the heat exchangers, and the discharge pipes are some common problems with OTEC [3].	The performance of the wave power drops significantly during rough weathers [9].	The plant has to be lowered to a depth of 110 m [10].	Limited number of sites to generate tidal power, but by placing the turbine in places with high tidal current more energy can be harvested [12].
Expenses	It needs large diameter pipes to be laid for a very high depth and so considered as expensive [3].	The cost of single devices is high. Integrating all the parts in the breakwater system increases the overall cost of the plant [9].	This is extremely costly, about 36 times more expensive than other conventional plants [13].	The energy return on investment for tidal turbines is predicted to be much higher than the most other energy technologies [14].
Effects on environment	This technology has not been tested on a large scale [3].Land planning issues may create a problem [3].	They cause air and noise pollution. The shoreline devices may disturb the beachgoers [9].	There are also some engineering problems in adopting this technology [13].	It can be placed underwater, thereby reducing air and noise pollution [15] Moreover, due to its modular nature, silt accumulation is prevented here [16].
Effects on marine life	Discharge has to be carried out at specific depths without affecting the marine life. For this additional construction, maintenance and expenses are needed [3].	The vibration caused by heavy machinery disturbs the seabed and marine life [9].	The problem with the protection of marine organisms from turbines and other machinery [13].	The turbine rotates very slowly and hence it won't damage the fish or marine life [16].

2.1.1 OTEC.

The OTEC systems use the temperature difference between warm seawater at the surface of the ocean and cold seawater at 800 – 1000 m depth to produce electricity by running a heat engine [3]. This technology is viable in the equatorial region where the year-round temperature differential is 20^{o}C [3]. OTEC system has not yet been used in Lakshadweep, but the Low-Temperature Thermal Desalination Plant (LTTD) which also uses the temperature differences for producing freshwater as condensate has been installed. Three desalination plants with 100 kiloliters/day capacity have been installed in Kavaratti (2005), Agatti (2008), and Minicoy (2010). The Lakshadweep administration requested the Indian government to install similar desalination plants at other six islands viz. Amini, Chetlet, Kadamath, Kalpeni, Kiltan, and Andrott. ESSO-NIOT has sent a detailed project report, but the proposal was not approved [3].

The OTEC system involves the construction of pipes at larger depths, which may affect the seabed. The transfer of cold water to the surface and warmer discharge in the ocean can disturb the aquatic life[3]. For an island, fishing and tourism are the major sources of economy. Implementation of OTEC systems is not recommended for these islands as they can highly affect the marine ecology.

2.1.2 Wave Energy.

Waves are caused by the wind blowing over the surface of the ocean. Wave power devices extract energy from the surface motion of ocean waves or from pressure fluctuations for power production [4]. A study on the feasibility of wave energy shows that more than 80 sites have wave energy potential along the Indian coast [15]. The islands of Lakshadweep are dominated by southwest monsoon during which the wave height goes up to 5m. Comparing to the average wave power at the location near main land, Lakshadweep sea has 40% more [17]. The Lakshadweep and the Andaman groups of islands have an annual wave power potential of 10 kW/m with 20 kW/m during the southwest monsoon periods [17].

A linear generator-based wave energy system has been planned for offshore A&N islands[18]. Indian Institute of Technology, Madras and NIOT developed India's first wave energy plant, and the upgraded version of the plant is in progress [19]. However, the drawback in opting for this type of energy production is the difficulties in initial installation due to cost, lack of ease of maintenance, noise and vibration disturbing the marine ecosystem [9,20].

2.1.3 Energy from Salinity Gradient.

Osmotic energy from salinity gradient is generated using the difference in the salt concentration of seawater [13]. The solutions with higher salt concentration have a higher pressure and vice-versa. When the river water and seawater are separated by a semipermeable membrane, freshwater naturally moves through the osmotic membrane towards the seawater, and the resulting pressure helps in rotating a turbine[13].

These commercial plants require a very large amount of membranes, which is the main economic barrier, as they account upto 80% of the total capital [21]. The first osmotic power plant in the world opened in Norway in the year 2009 [22]. India is yet to try osmotic power generation.

2.1.4 Tidal Energy.

The world's first tidal power plant was commissioned in France across the Rance river in 1964. The plant with a capacity of 240 MW with 24 bulb turbines, each having a capacity of 10 MW, is still working efficiently. There are many small tidal power plants constructed and running successfully all over the world [23]. The tides are a strong source of renewable energy, which can serve remote islands having strong tidal currents. The energy of the tides can be calculated using the equation,

$$E = 0.5\rho g A h^2 \qquad (1)$$

Taking an average (ρg) = 10.15 kNm^3 of seawater, the tidal energy obtained for a tide cycle per square meter of the ocean surface is 1.4 h^2 watt-hour (5.04h^2KJ). The energy potential of tidal power in India is about 8000 - 9000 MW [24]. The tidal amplitude or tidal range is the average difference between the water levels during high and low tides. For an economical operation in Tidal energy generation the site must have a tidal range of 7 m and above [25]. The potential locations in India are in the Gulf of Kambay and the Gulf of Kutch, having a maximum tidal range of 8 m and 11 m respectively, whereas their average tidal ranges are 5.23 m and 6.27 m and their energy potentials are 1200 MW and 7000 MW respectively. Similarly, the Sundarbans in the Ganges delta has a good potential of nearly 100 MW with a maximum tidal range of approximately 5 m and an average tidal range of 2.97m [24].

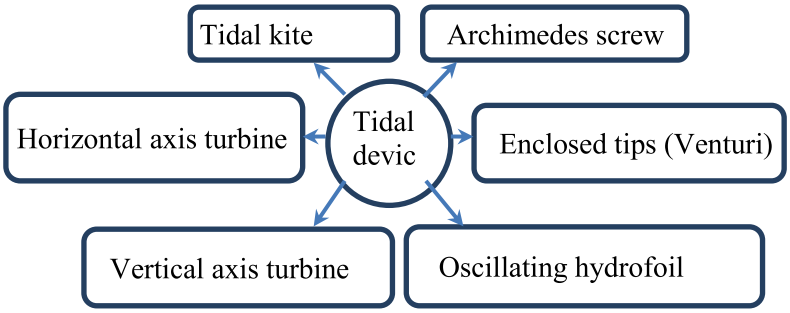


Figure 2. Types of tidal devices.

There are six major types of tidal energy converters which are shown in the Figure.2, most exploiting the current induced by the tide. The horizontal axis current turbine resembles a wind turbine running in seawater. The moving stream causes the turbine to rotate and that generates electricity [25]. The axial axis turbine is commonly the most hydro – dynamically efficient turbine when it is in –lined correctly to the stream. A vertical axis turbine is mounted on a vertical axis, and the turbine rotates around the vertical axis to produce electricity[26]. The oscillating hydrofoil, is subjected to lift by the tidal streams flowing and is attached with an arm to a generator which converts mechanical energy into electrical energy [26].The venturi type of machines has its turbine inside a duct where the flowing water is concentrated into the funnel-like opening. The turbine can either be driven directly by the flow of current or the induced pressure differential can drive the air turbine and thus generate electricity[26]. The Archimedes screw consists of a central cylindrical shaft surrounded by a helical surface. The moving stream turns the helical surface which turns the turbine[26]. In tidal kites, the speed of the water through the turbine is increased by the swing of the kite attached to the seabed. Here, the turbine is attached to the bottom of the kite [26].

2.1.5 Marine Current Energy.

The tidal or marine current power has relatively long life and lower cost of operation. For example, the tidal power plant installed in 1964 in France with an initial cost of $66 million is generating electricity for over 300,000 homes even today [27]. However, the cost of this energy system increases when subjected to violent winds and waves.

Marine currents can be classified into two categories: global currents, which are caused by temperature and salinity differences between two neighbouring masses of water, and tidal currents that are caused by the movement of the celestial bodies in the solar system [28]. Table 1 shows the merits of tidal or marine current turbine systems over other systems. Unlike other renewable energy, marine current energy is highly predictable, and a consistent source of kinetic energy exists in this system. Ocean currents have a relatively constant and directional flow, which is in contrast to the rectilinear (reversing) tidal current [29]. One of the best sites to harvest marine current energy is between the islands where strong water currents exist [29]. The basic structure of a tidal turbine system is shown in Figure 3.

The turbine can be installed at a place with tidal ranges of more than 7 m or at the place experiencing a current speed of greater than 1.25 m/s to acquire sufficient energy [30,31]. NIOT has planned to install a 2-5 kW marine current turbine module in an Andaman site having a current speed of 1.2m/s[32] This study focuses on marine current energy generation to be carried out in the Lakshadweep islands.

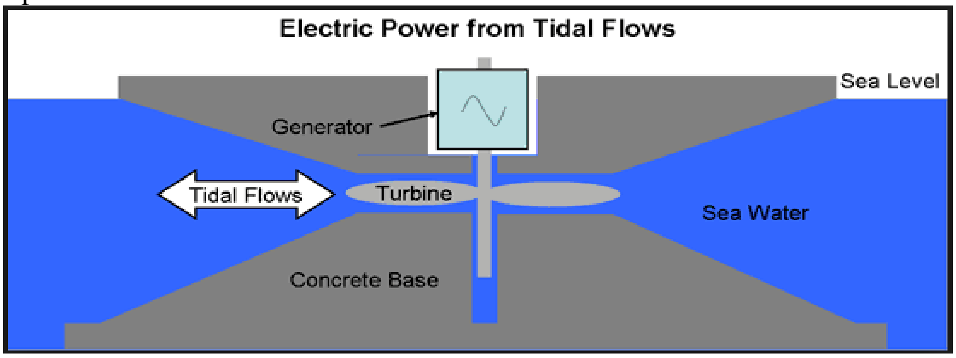


Figure 3. Energy from tidal stream [33].

3. Results

3.1 Indian Islands and its Energy Scenario

India has two main groups of islands. They are the Andaman and Nicobar (A&N) islands and the Lakshadweep islands. The A&N islands are located in the Bay of Bengal, and the Lakshadweep islands are located in the Arabian Sea. The maps of the islands are shown in Figure. 4 [17,34,35].

3.1.1 Lakshadweep Island.

The Lakshadweep islands are situated at a distance ranging from 200 to 400 km from Kochi, Kerala, a southwestern coastal state in India [2]. The island is classified into three groups, namely, Aminidivi, Laccadive, and Minicoy. Among these groups are ten inhabited islands called Agatti, Amini, Androth, Bitra, Chetlat, Kadamat, Kalpeni, Kavaratti, Kiltan, and Minicoy out of the 36 islands [17]. The total area of Lakshadweep is 32 km^2, the coastal length is 132 km, and the lagoon area is 4,200 km^2. The total population is about 64,473 as per the 2011 census [1]. Table 2 gives more details on the households in Lakshadweep.

Table 2. Details of households in Lakshadweep [1].

Total Households *Normal*	*Institutions*	No exclusive rooms	1 room	2 rooms	3 rooms	>3 rooms
11,541	33	55	804	2,099	2,946	4,799

The Lakshadweep islands are comparatively less prone to natural calamities. Earthquakes have not been reported to have occurred there, but the area has moderate seismic activities and is classified under the moderate damage risk zone of MSK VII in the Vulnerability Atlas of India [2]. The Indian Ocean earthquake and tsunami that happened in the year 2004 did not have any impact on these islands. In the past 166 years, the islands were affected only by seven storms and few are reported till 2015 [17]. However, Lakshadweep faces some serious problems like coastal erosion and sea-water inundation due to high monsoonal activity. Studies are being carried out for reef strengthening that would protect the islands from severe wave activities [35]. High wind is one of the major reasons for the rough waves which cause coastal erosion. The northern part of the islands is influenced by the Indian coastal - winds because of their proximity to the mainland, and the southern part by equatorial winds. The northeast monsoon usually occurs during October to January, while the southwest monsoon occurs during May to September. During the southwest monsoon, the littoral current is south to north. During the northeast monsoon and pre-monsoon periods, it is north to south [36].

Present Energy Scenario: The Lakshadweep administration procures 13,000 kiloliters of High-speed Diesel (HSD) per year. In addition, Bharat Heavy Electricals Limited (BHEL) has set up nine SPV's (Solar Photovoltaic Cells) with an installed capacity of 950 kW in nine islands, but they operate at only 40% capacity. The details of different power plants with their energy capacity for different islands in Lakshadweep are shown in table 3 [37]. The approximate power consumption of the island is 16.410 MW from Diesel Generator (DG) sets and 2.165 MW from SPV's.

At present, the expensive DGs cater to the energy need of the island. The DGs are not only the source of energy but also the source of air pollution because of the harmful gas emissions while running. The DG sets contaminate the islands' porous soil and water due to oil seepage from storage tanks [38].

Table 3. List of power plants in the Lakshadweep islands [37].

Island	Installed capacity (kW)	
	DG set	SPV
Minicoy	2800	210
Kavaratti	3200	760
Amini	1900	100
Andrott	2500	320
Kalpeni	1250	100
Agatti	1600	100
Kadmat	1400	260
Kiltan	1000	100
Chetlat	500	100
Bitra	80	50
Bangaram	180	50
Suheli	-	15

The figures are as of December 31, 2012.

3.1.2 Andaman and Nicobar Islands.

Andaman and Nicobar islands, with a total area of 8,249 km^2, are located in the Bay of Bengal. This UT consists of 319 islands, in which, the Andaman group of islands comprises of 258 islands and the Nicobar group comprises of 61 islands. The coastal line extends up to 1,962 km [39]. A ten-degree channel divides the Bay of Bengal and the Andaman Sea [1]. The islands have a population of 380,581 as per the census in the year 2011. These islands are prone to natural disasters like tsunami, earthquakes, volcanic activities, cyclones, and floods. Areas like Car Nicobar, (add) are vulnerable to flooding because of the flatlands [40].

Present Energy Scenario: Similar to the Lakshadweep islands, DG sets are the major source of energy in these islands. The islands have 41 diesel powerhouses with varying capacities. The DG sets and a hydropower station at Kalpong have a collective capacity of 68.5 MW [41]. BHEL had installed two SPV power plants of 50kW capacity in Neil and Havelock Islands[42]. The average annual unit production of 100 KWp SPV is 100,000 per year. A few powerhouses are listed in table 4. The power generation and the current energy scenario are given in Tables 5 and 6 [43]. A hydropower plant of 5.25 MW capacity at the Kalpong river in North Andaman is operational since 2001[44]. In addition, an OTEC system is also planned by the Indian Navy [44].

Table 4. List of the powerhouses.

Name of the powerhouse	Capacity (kW)	Duration of Supply (hrs)
Andaman Islands		
Smith Island	24	15-16

Khep	5250	24
Sita Nagar	1360	24
JagganathDera	24	15-16
PachimSagar	50	15-16
Hanspuri	12	15-16
Rangat Bay	5075	24
Long Island	380	24
Stait Island	75	15-16
Havelock	1330	24
Neil	560	24
Baratang	380	24
Ipp	20000	15-16
Shol Bay	24	24
Chatham	12500	24
Phoneix Bay	9018	24
Rut Island	12	15-16
Dugong Creek	45	15-16
Hut Bay	4200	24
Nicobar Islands		
Car Nicobar	2520	24
Chowra	128	15-16
Terrasa	290	15-16
Pilpillo	24	15-16
Katchal	568	24
Kakana	24	15-16
Kamorta	768	24
Champion	245	24
Champbell Bay	2962	24

Table 5. Details of power generation in the major islands of A&N.

Installed capacity	68.46 MW
Number of powerhouses	42
High tension lines	972 kms
Low tension lines	2727 kms
Distribution transformers	553
Consumers	81,000
Peak demand	37 MW
Energy production annually	201 MU
Diesel consumption annually	48,000 kilo-liter

Table 6. The present energy scenario in the major A&N islands.

Name of the Island	Installed Capacity (MW)	Annual Generation (MU)	Peak Demand (KW)
North Andaman	6.86	9.79	2461
Middle Andaman	6.36	16.4	2699
-Long Island	0.39	0.5	120
-Baratang	0.38	0.39	210
South Andaman	41.28	151.57	27560

Journal of Physics: Conference Series **1716** (2021) 012007 doi:10.1088/1742-6596/1716/1/012007

-Neil Island	0.56	1.01	270
-Havelock	1.33	2.58	444
Little Andaman	4.2	6.5	1590
Car Nicobar	2	4.95	1447
Nancowry	2.1	3.54	686
Great Nicobar	3	3.67	691
Total	68.46	200.9	38178

Table 7 shows the different ocean energy systems that are already implemented or being implemented in India.

Figure.4 Islands of India. [35] [45].

Table 7. Efforts done in the Indian Ocean along the Indian coast.

Location	System	Year	Capacity (MW)	Description	References
Panchapada	Tidal	1983	3	Project reports were prepared, but	[44]

River, Balasour district, Odisha				have not been implemented.	
Gulf of Kutch, Gujarat	Tidal	1988	900	The feasibility study was made, but it was not found to be commercially viable.	[44]
Andaman & Nicobar Islands	Tidal	1992	-	The project report has been prepared, but has not been implemented.	[46]
Durgaduani creek, Sunderbans	Tidal	2008	3.75	Due to high tender cost (INR 238 crores against original estimation of 48 crores), the project has been discontinued.	[46]
Durgaduani creek, Sunderbans	Tidal	2008	3.75	Due to high tender cost (INR 238 crores against original estimation of 48 crores), the project has been discontinued.	[44]
Mandavi, Gulf of Kutch, Gujarat	Tidal	2011	50	GPCL in collaboration with Atlantis Corporation is working on this pilot project.	[44]
Rutland Island, Andaman Islands	Marine current	2016	0.0001 (100 W)	This is a trail project for implementing a 5kW plant. The setup required several modifications, yet the entire device was successfully installed by National Institute of Ocean Technology (NIOT) as a floating system.	[47]
Tuticorin, India	OTEC	1998	1	The NIOT with the help of Saga University optimized this closed loop OTEC system based on the temperature and bathymetric profiles in 1998.	[48]
Vizhingam, Tiruvananthapuram	Wave energy	1983	0.15	It was a successful installation during the pilot stage of device development and has been a successful demonstration plant. But slowly it went out of use from 2011.	[49]
Thangaserry, Kollam, Kerala	Wave energy	~1995	1.5	The success of Vizhingam project leads to design this project at the breakwater of the fishing harbor in Thangaserry.	[38]

3.2. Beneficiary Island

The Andaman has a tidal range of 2–5m with periodic sea level depressions. Although it is higher than that of Lakshadweep which has 1.4 m as the highest, the A&N islands are more prone to natural disasters [40] and it may be a challenging task to build the tidal power energy system. The Lakshadweep islands have a coastline of 132 km with large coral reefs, which act as submerged breakwaters to protect the islands. The wave and tide recorder deployed at the Kachery jetty on Kavaratti island recorded the maximum tidal range of 1.4 m so far.

A minimum current speed of 1.25 m/s that can fetch 1 kW/m^2 is required for a practical power plant to be economically viable [50]. The potential site should have a sustained current speed of above 1.25 m/s at a sufficient depth of 15 m to 50 m [51] to install a turbine. The inner shelf currents of Lakshadweep Sea are generally weak, and the current speed varies up to 0.7 m/s. The eastern part of the islands has a steep nearshore slope, which is suitable for constructing a power plant at a short distance from the shore to reduce the transmission cost [17]. In an open channel, the speed of the tide ebbs and flows may be less, but the tidal movements around the islands while passing through narrow channels can reach high velocities [52]. In this study, the Lakshadweep islands are chosen for evaluating the feasibility of marine current energy. A preliminary analysis of the site has been done in this study with the help of real-time data of Indian National Center for Ocean Information Services (INCOIS).

3.3 Data Collection and Analysis

Lakshadweep has mixed semidiurnal tides which means that the area experiences too high and too low tides of different sizes on every lunar day [17]. The current speed data are collected from various buoys located around the Arabian Sea and the Bay of Bengal. They are named as ADxx, BDxx, CBxx and are shown in Figure 5. Here the xx refers to the two digits to identify an individual buoy [53].

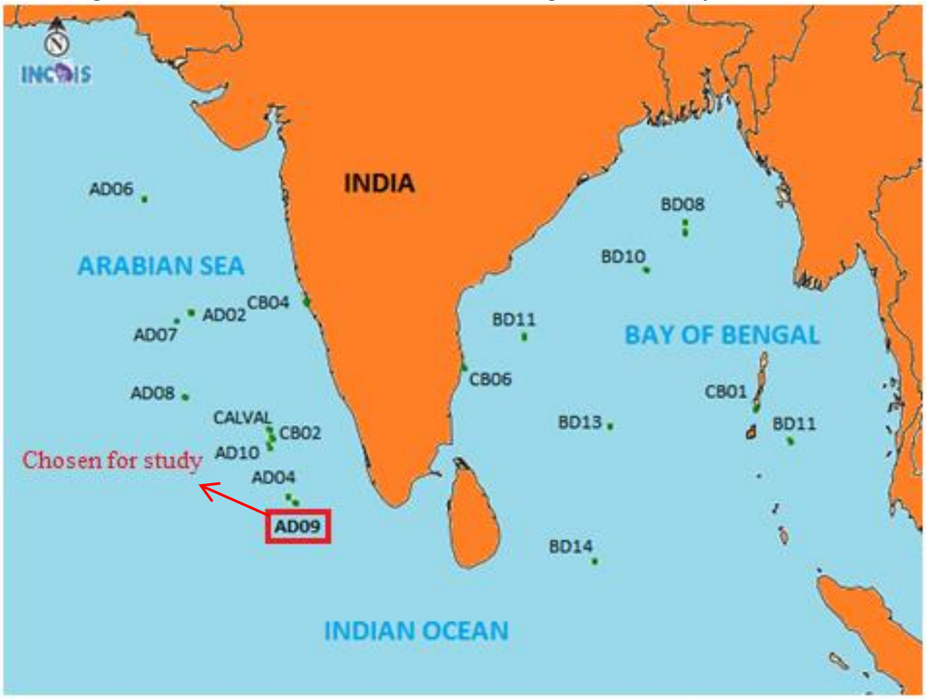
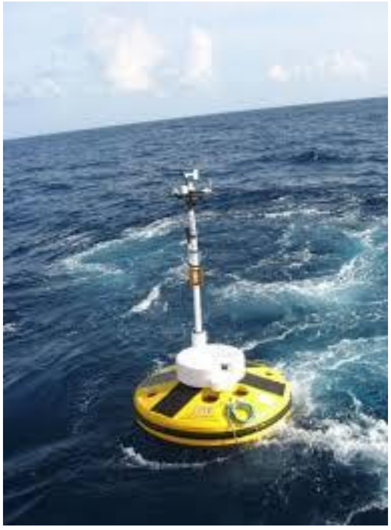


Figure 5. Moored buoys located around India [54].

A detailed study on the history of the site, climate, hydrodynamics etc. helps in locating the suitable location for a power plant. ESSO-INCOIS, an autonomous unit of the Earth System Science Organization, works under the Ministry of Earth Sciences controlled by the Government of India. They have deployed many buoys in the Indian waters for measuring the data on air pressure, air temperature, conductivity, current speed, current direction, humidity, salinity, SST, wave height, wave period, wave direction, wind speed, and wind direction. The current speed data which is needed for the present study is recorded in a three-hour interval for up to 100 m depth [54]. The current speed and the depth of the site determine the efficiency of the turbine. The arrangement of a typical moored buoy is shown in the Figure.6.



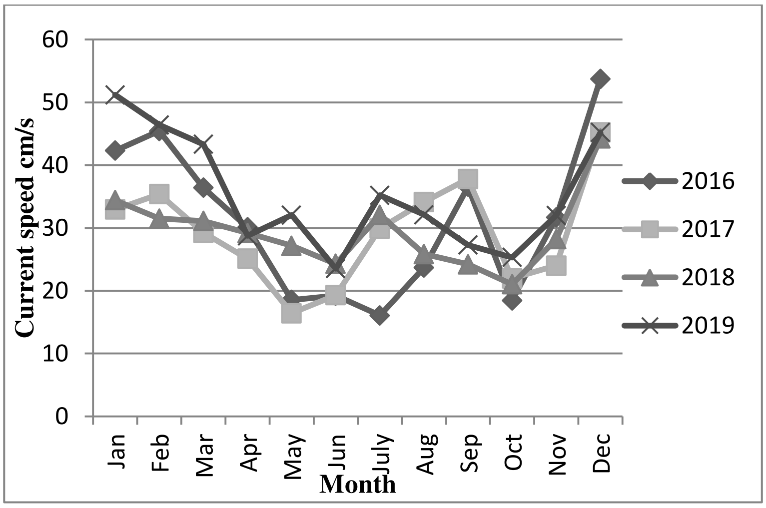


Figure 6. Moored buoy [54]. **Figure 7**. Average monthly current speed measured by AD09.

The four year current speed data at AD09 was analysed and it is show in the figure 7. The trend shows that maximum speed of 0.5m/s is attained in the month of December and January. The average current speed at the location was found to be 0.3m/s.

4. Discussion

4.1. Power Estimation for the Minicoy Island

Minicoy, which lies between 8˚15' N to 8˚20'N latitude and 73˚01' E to 73˚04'E longitude (figure.2), is the southernmost island of Lakshadweep, situated at a distance of 398 km southwest of Kochi, Kerala state of the Indian mainland [55]. It has a lagoon of about 6 km^2 and it protects the island from the southwest monsoon currents [36]. The area of the island is 4.37 km^2 with the population of 10,447 as per the 2011 census [56]. The island has an elevation of 3-4 m from the mean sea level. The bathymetry profile taken from a report by NIOT is shown in figure 8. The depth of the ocean increases after 200 m and it becomes more than 500 m deep at a distance of 900 m from the shoreline.

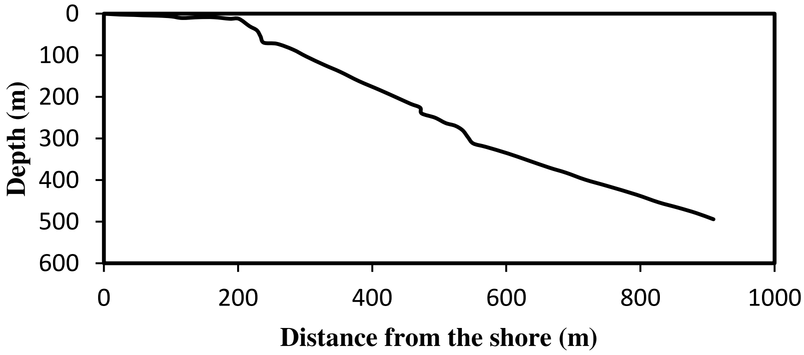


Figure 8. The bathymetry profile of the Minicoy beach [57].

4.2 Estimation of power output from the turbine

The extractable power output from the turbine can be estimated by,

$$P_e = C_{pe}.P \quad (2)$$

Where C_{pe} is the power coefficient and it is 0.45 for a horizontal axis turbine [58].

The power available from the stream of water in the absence of significant changes in depth or elevation is given by,

$$P = \frac{1}{2}\rho A_1 V^3 \quad (3)$$

Where A_1 is the rotor's cross section. [59–61]

This shows that energy extraction is highly sensitive to velocity. For a horizontal axis turbine having a rotor of 1 m diameter, the possible power flux produced and the extractable amount of power during various current speeds can be estimated from the equation 2 and are shown in table 8.

Table 8. Current speed and possible power.

Current Speed (m/s)	0.1	0.2	0.3	0.4	0.5
The power density (kW/m^2)	0.00	0.00	0.01	0.03	0.06
Extractable power from horizontal axis turbine (kWh/day)	0.00	0.03	0.11	0.27	0.54

From the four years' data, it is seen that Minicoy has an average monthly maximum current speed of 0.3 m/s and the turbine can produce a power of 0.11kWh/day. For the maximum current speed of 0.5m/s the extractable power from a horizontal axis turbine is 0.54kWh/day. Although the output looks very low, energy generation can be made possible using advanced technologies in turbine design that are also proven in many low current speed location throughout the world [62–65].

4.3 Power production and delivery to the Island

By predicting the strength and the speed of the tidal/marine current well in advance, it is easy to supply the power to the grids. As the speed and the strength of the ocean currents are not constant, it is necessary for every marine current turbine to have a control system for efficient power production. The turbines can be either controlled by a PI or PID control system. Figure 9 shows the marine/tidal current turbine system with Doubly Fed Induction Generator (DFIG) having the PI controller. In DFIG, the power electronic interface controls the rotor currents to achieve the variable speed necessary for maximum energy capture in variable current speed.

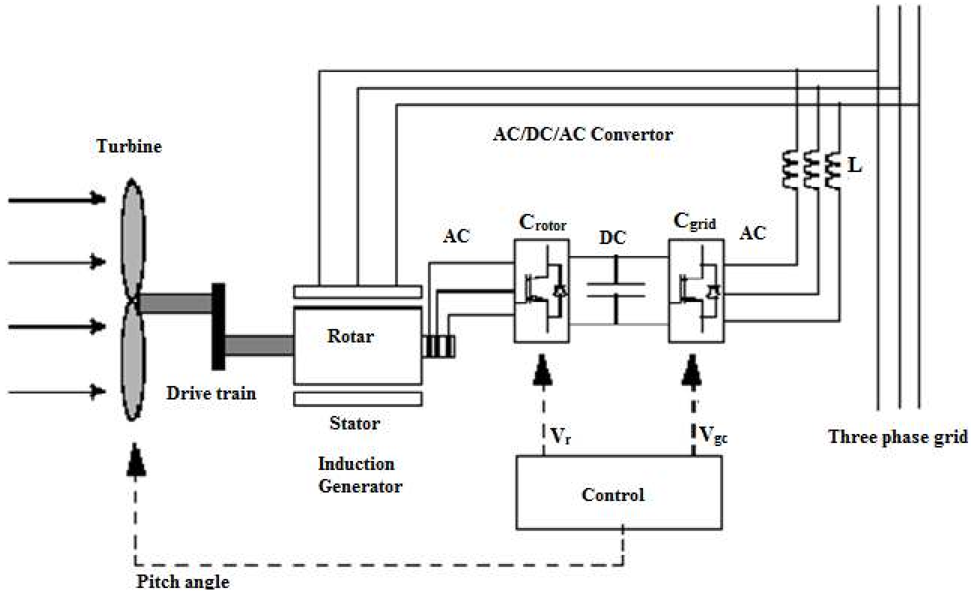


Figure 9. Tidal turbine using a generator [60].

The output from the drive train is connected to the generator. The main requirement in any power transmission system is the precise control of active and reactive power flow to maintain the system voltage stability [66]. A current source or a voltage source converter can serve the purpose.

The tidal or marine current turbines can be either placed on the sea floor or attached to a monopole foundation or anchored and allowed to float in the tidal stream. Depending upon the size of the devices, a number of tidal turbines can be installed and interconnected to make a tidal farm. The power generated by the turbines can be carried by power cables and underwater cables. Grid synchronization can be brought through variable speed drive and a step-up transformer for a suitable voltage level.

The submarine electrical cables can transfer the electric power to the shore. The cable runs to the interconnection substation that can be as small as 25 m^2 from which a transmission grid supplies power to the consumers. The control and monitoring of the devices can be done remotely using fibre optic cables or other communication systems [67]. The overall working of the tidal or marine energy system is shown in the figure 10 [66].

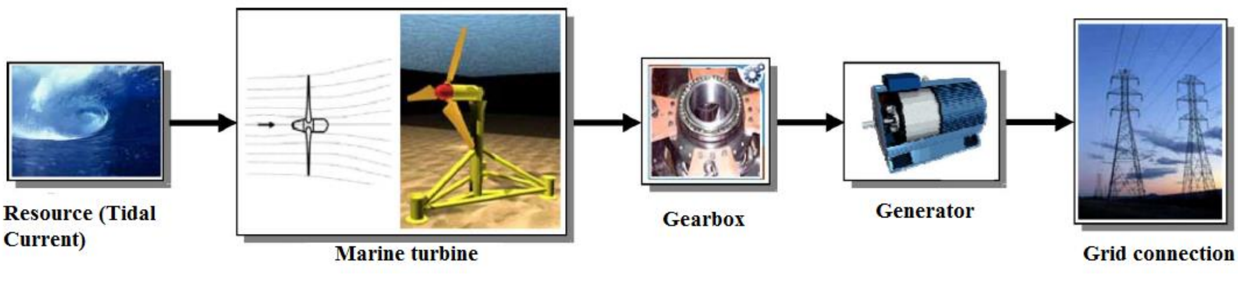


Figure 10. A global scheme for marine current energy harvesting and supply [66].

5. Conclusion

In this article, a detailed study has been attempted to identify and implement the right marine energy system for the remote Indian islands. A preliminary analysis of different ocean energy systems was made, and the most viable system and location for generating power through ocean currents were chosen. The study is based on a literature survey and data analysis. A site near Minicoy has been identified from the data of the buoy AD09 deployed by INCOIS.

A turbine needs at least 1.25 m/s current speed for power generation, but it was found difficult to achieve it near Lakshadweep throughout the year. However the bathymetry profile shows the availability of sufficient depth near the shore for installing a turbine. Hence, the marine turbine technology can be a suitable option for the Minicoy Island with the improvement in the turbine technologies. Further studies is required to widen the sources of information for the currents beyond the current buoy and literature information, assess the sea floor, optimize the location of the axial axis turbines and conduct a full socioeconomic study that includes the local people attitude.

Nomenclature

Abbreviations

A&N	Andaman and Nicobar
BHEL	Bharat Heavy Electricals Limited
DG	Diesel Generator
HSD	High-speed Diesel
SPV	Solar Photo Voltaic
MSK	Medvedev–Sponheuer–Karnik scale
MU	Million Unit
OTEC	Ocean Thermal Energy Conversion
OWC	Oscillating Water Column
SST	Sea Surface Temperature
NIOT	National Institute of Ocean Technology

Symbols

A	Sea area under consideration (m^2)
A_1	Cross section area of the rotor considered (m^2)
C_{pe}	Power coefficient for horizontal axis rotor = 0.45
E	Energy
G	Acceleration due to gravity
H	Tidal amplitude (m)
P	Kinetic energy flux
Pe	Extractable power output per unit area (kWh/day)
V	Velocity of currents (m/s)
P	Density of seawater (kg/m^3)

References

[1] Census of India 2011 District census handbook
[2] Diaster management division of India 2005 Report of the National Task Force for a Special Study of Lakshadweep Islands to Assess Vulnerability to various Hazards and Suggest Mitigation / Prevention Measures *Disaster Manag. Div. India*
[3] Kempener R and Neumann F 2014 Ocean Thermal Energy Conversion Technology Brief *Int. Renew. Energy Agency*
[4] U.S. Department of the interior 2015 Ocean Wave Energy *Bur. Ocean Energy Manag.*
[5] Rourke F O, Boyle F and Reynolds A 2010 Tidal energy update 2009 *Appl. Energy* **87** 398–409
[6] Kempener R and Neumann F 2014 *Tidal Energy Technology Brief*
[7] US Department of Commerce 2015 Ocean Facts *Natl. Ocean. Atmos. Adm.*
[8] Thorpe T 1999 *A Brief Review of Wave Energy-A report produced for The UK Department of*

Trade and Industry
[9] Rinkesh 2015 Advantages and disadvantages of wave energy *Conserv. Energy Futur.*
[10] Harrysson T, Vensson D L and Jesper J 2016 Osmotic Energy *Exergy*
[11] Greentumble 2015 Advantages and disadvantages of wave power *Greentumble Energy*
[12] Boyle G, Everett B and Alexander G 2015 *Renewable energy power for sustainable future* (Oxford)
[13] Mishra A 2013 Osmotic Power Huge Source of Renewable Energy *Int. J. Sci. Eng. Res.* **4**
[14] Fraenkel P L 2006 Tidal Current Energy Technologies *lbis* **148** 145–51
[15] CRISIL and IITM 2014 *Study on Wave and Tidal Energy in India- Potential and Proposition of a Roadmap*
[16] Wikispaces 2015 Advantages and Disadvantages of Tidal Current Technologies *Wikispaces*
[17] Prakash T N, Nair L S and Hameed T S S 2015 *Geomorphology and Physical Oceanography of the Lakshadweep Coral Islands in the Indian Ocean* (Springer)
[18] Tidal Energy Today 2015 Islands to get power from waves *Offshore energy*
[19] Government of India 2014 Study on Tidal & Waves Energy in India: Survey on the Potential & Proposition of a Roadmap *Minist. New Renew. Energy, Gov. India*
[20] Ruud Kempener and Frank Neumann 2014 Wave Energy Technology Brief *Int. Renew. Energy Agency*
[21] Kempener R and Neumann F 2014 Salinity Gradient Energy Technology Brief *Int. Renew. Energy Agency*
[22] REUK 2014 Osmotic Power Plant Opened *REUK.co.uk - Renew. Energy Website*
[23] Zainol M Z, Ismail N and Zainol I 2017 A REVIEW ON THE STATUS OF TIDAL ENERGY TECHNOLOGY May-June *Sci. Int.* **29(3)** 659–67
[24] Ashfaq A and Sharma P 2011 Tidal Energy as a Potential Energy Source *J. Ind. Pollut. Control* **27** 39–41
[25] Gorlov AM 2001 *Tidal Energy* (Boston Massachusetts, USA)
[26] The European marine energy centre limited 2011 Tidal Devices *EMEC*
[27] Greenmatch 2020 Tidal energy and Wind power as Renewable energy sources in the UK
[28] Sudarsan J 2015 ClearIAS Movements of ocean water : Waves , Tides and Ocean currents movements of ocean water : The classification *Clear IAS*
[29] Zarubin B 2015 *Ocean Current Energy: Underwater Turbines* (Stanford Uiversity)
[30] Ocean energy council 2015 Tidal energy *Ocean energy Counc. Inc*
[31] Thomas A R B, Khan P S Z and Gillman S B J 2016 Current tidal power technologies and their suitability for applications in coastal and marine areas *J. Ocean Eng. Mar. Energy* **2** 227–45
[32] NIOT 2016 *NIOT/MoES's hydrokinetic turbine generates electricity using ocean currents*
[33] Power H and Turbines W 2019 Battery and Energy Technologies Hydroelectric Power 1–6
[34] India G of 2019 Map of Andaman and Nicobar Island 2019
[35] Prakash T N, Nair L S and Varghese T I 2014 Shoreline changes and reef strengthening at Kavaratti island in Lakshadweep archipelago - A case study *Indian J. Mar. Sci.* **43**
[36] Anandaraj N 2002 *Petrography, Geochemistry and Diagenesis of Coral Deposits of Kavaratti and Minicoy Islands, Lakshadweep, India* (Cochin University of Science and Technology)
[37] Lakshdweep Government 2011 Power plants *Powerlac, Gov. India*
[38] Lakshadweep Government 2011 Lakshadweep State Development report *Plan. Comm. Gov. India*
[39] A&N Government 2011 General Information: Andaman and Nicobar Islands *Andaman Nicobar Islands Adm. Gov. India*
[40] A&N Government 2012 *Diasater Management Plan- Andaman and Nicobar Islands*
[41] A&N Government Present status of Renewable source of energy *Electr. Dep. Nicobar Islands, Gov. India*
[42] Electricity Department of Andaman 2019 Renewable energy in Andaman *Andaman Nicobar*

Islands Adm. Gov. India 1–4
[43] A&N Government 2012 Power Houses- Andaman and Nicobar Islands *Electr. Dep. Nicobar Islands, Gov. India*
[44] A&N Government 2012 Policy for Power Generation through New and Renewable Energy Sources in Andaman and Nicobar Islands *Andaman Nicobar Islands Adm. Gov. India*
[45] Press Information Bureau 2014 Desalination Plants *Press Inf. Bur.*
[46] Indian Energy Sector Tidal Energy in India-Potential, Projects and Developments *Business*
[47] NIOT 2015 Ocean structures *Natl. Inst. Ocean Technol.*
[48] Kangare D, Bansode S, Dhiwar S, Giri K and Katare P 2016 Indian Scenario of Wave Energy Technology **6** 2014–7
[49] Ministry of Earthscience 2015 Coastal Zone and Islands *Natl. Inst. Ocean Technol.*
[50] Laplante D and Wang Y 2015 *Renewable Energy Resources : Tidal and Jet stream Energies Submitted by :*
[51] Fraenkel P L 2002 Power from marine currents *Proc. I MECH E Part A J. Power Energy* **216** 1–14
[52] National Geospatial intelligence agency 2017 Tides and Tidal Currents
[53] INCOIS In-situ data *Indian Natl. Cent. Ocean Inf. Syst.*
[54] INCOIS Ocean Data and Information System *Indian Natl. Cent. Ocean Inf. Syst.*
[55] INCOIS Minicoy Island, Lakshadweep *Natl. Informatics Cent.*
[56] Census of India 2011 District Census Handbook Lakshadweep *Census Of India 2011*
[57] Atmanand M A, Phanikumar S V S and Ramanamurthy M V 2013 Technical report on design and execution of desalination plants in Minicoy and Agatti *Natl. Inst. Ocean Technol.*
[58] Karthikeyan T, Ezhilsabareesh K, Samad A, Venkatesan N and Avital E J 2016 Parametric analysis of a tidal current turbine using CFD techniques *Prog. Renew. Energies Offshore - Proc. 2nd Int. Conf. Renew. Energies Offshore, RENEW 2016* 553–8
[59] Ai K, Avital E J, Korakianitis T, Samad A and Venkatesan N 2016 Surface wave effect on marine current turbine, modelling and analysis *Proc. 2016 7th Int. Conf. Mech. Aerosp. Eng. ICMAE 2016* 180–4
[60] Singha O, Venkatesan N, A.Samad and E.J.Avital 2016 Modeling and controller implementation of tidal turbine for Indian remote islands *2016 7th International Conference on Mechanical and Aerospace Engineering (ICMAE)*
[61] Bahaj A S 2011 Generating electricity from the oceans *Renew. Sustain. Energy Rev.* **15** 3399–416
[62] Encarnacion J I, Johnstone C and Ordonez-Sanchez S 2019 Design of a horizontal axis tidal turbine for less energetic current velocity profiles *J. Mar. Sci. Eng.* **7**
[63] Tian W, Mao Z and Ding H 2018 Design, test and numerical simulation of a low-speed horizontal axis hydrokinetic turbine *Int. J. Nav. Archit. Ocean Eng.* **10** 782–93
[64] Fraenkel P L 2007 Marine current turbines: Pioneering the development of marine kinetic energy converters *Proc. Inst. Mech. Eng. Part A J. Power Energy* **221** 159–69
[65] Lee M Q, Lu C N and Huang H S 2009 Reliability and cost analyses of electricity collection systems of a marine current farm-A Taiwanese case study *Renew. Sustain. Energy Rev.* **13** 2012–21
[66] Multon B 2012 *Marine Renewable Energy Handbook* (Wiley)
[67] Benelghali S, Benbouzid M, Charpentier J F, Benelghali S, Benbouzid M, Frédéric J, Generator C, Benelghali S, El M, Benbouzid H and Member S 2012 Generator Systems for Marine Current Turbine Applications : A Comparative Study To cite this version : Generator Systems for Marine Current Turbine Applications : A Comparative Study *IEEE J. Ocean. Eng.* **37** 554–63

Acknowledgements
The authors would like to acknowledge the support of DST-UKIERI (Grant no: DST/INT/UK/P107/2014) to conduct this research. The authors would also like to thank INCOIS for providing the in situ data from various buoys at different locations near the Indian coast.