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Tidal Current Energy for Indian Coastal Lines – A State Art of Review

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

[1]KCG College of Technology, Chennai, India
[2]School of Electrical Engineering, VIT University, Chennai, India
[3]Department of Ocean Engineering, IIT Madras, India
[4]Queen Mary University, London, United Kingdom
*Corresponding author E-mail: nithya.v@vit.ac.in

Abstract. India has about 7500 km of coastal lines with a significant potential to harvest marine energy. Tidal energy, one of the types of marine energy that emerges has a practical option to supply reliable and renewable energy to the Indian coastal areas. This paper focuses on tidal current turbines that can be adapted to various potential sites available along Indian coasts. Tidal energy projects all over the world and the type of turbines used by their applications are presented. This is followed by preliminary analysis of the Indian sites that includes current speeds and depth, possible adoption of current tidal current technology to those sites and the likely power output. Finally, challenges facing those who adopt the current technology are briefly discussed.

1. Introduction

India with a fast growing population requires a diverse power generation to comply with the demand for energy in the country. The growth in the power sector during 2009-10 to 2016-17 is shown in figure 1[1]. The present installed capacity of various renewable energy sources in India are shown in figure 2 [1].

Present clean energy sources installed in the country are not sufficient to replace the whole or partial conventional energy plants polluting air. So adopting more renewable energy sources is of great importance for overcoming emerging issues of environmental concerns in India [1]. Marine energy is a valuable source of energy to the Indian economy due to the long Indian coastal line, but it requires more attention and development to make it valuable for the energy sector [2]. Generally the generation of power from marine energy can be classified as ocean thermal energy, current, wave, tidal energy and from salinity gradients, all are completely renewable and reliable source for efficient energy generation.

There are several review articles on tidal turbine technologies and their suitability for various places [3][4][5] but in this article the discussions are focused on suitable Indian sites and the kind tidal current turbines that may be appropriate for those sites. This paper will give some trace for researchers to decide the type of turbines to be adopted while implementing tidal energy technologies in India.

A Tidal current turbine can be described as an underwater wind mill with blades rotating at slow speed. It can be operated at water depths between 35 and 100 m .This technology neither creates visual or audible impact near the shore nor affects the ship route if it is well placed underwater [6]. The tidal turbines are of four types. They are vertical axis, horizontal axis, oscillating hydrofoil and venturi effect. The first two are current turbines and the others can exploit the rise and fall in the water level . figure 3 gives a brief understanding of the different types of turbines existing in the world to extract energy.

This paper is organized as follows: Section 2 generally describes tidal energy aspects and Section 3 describes several types of commercially available turbines of various worldwide companies and operation envelopes in terms of suitable current speeds and water depth. Section 4 gives a detailed study of potential sites in Indian coastal lines to show the feasibility of installing tidal turbines in the near future, where site's tidal current speed and water depth are leading parameters in choosing the appropriate type of a tidal current turbine. Conclusions are given in Section 5.

2. Tidal Energy

Tides occur due to the existence of gravitational force between the Sun, the Earth and the Moon. The distance between the Moon and the Earth is shorter, and so the force between them is higher than that of between Sun and the Earth. So the tide action will be higher during the night than in the day time [7]. Tidal currents are formed when the water move horizontally due to the tidal action in the shore. The current which moves towards the land are known as flood tides and which moves away from the sea are known as ebb tides [8]. Due to the change in gravitational force between the Earth and the celestial bodies the high and low tides occur. Tidal range is defined as the difference between high tides and low tides. Figure 4 represents the tidal range at the time of high and low tides near the seashore [9]. Generally the energy generated out of the tidal action in water is known to be as tidal energy.

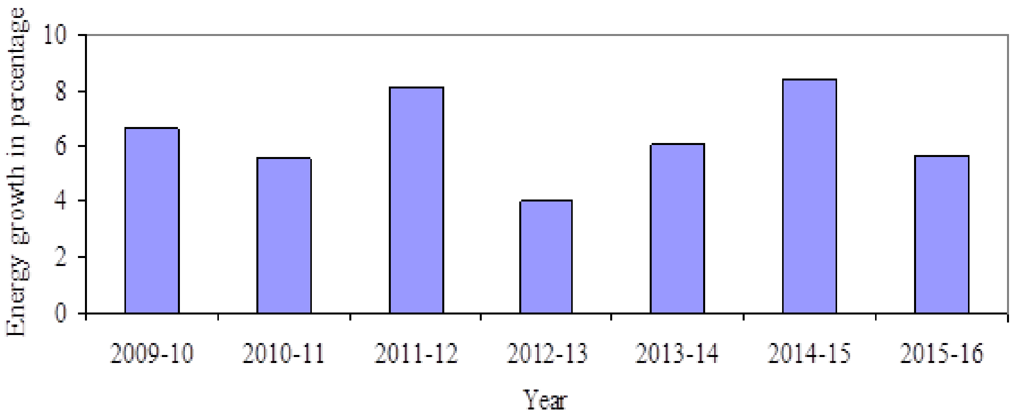

Figure 1. Growth in Indian Power sector [1].

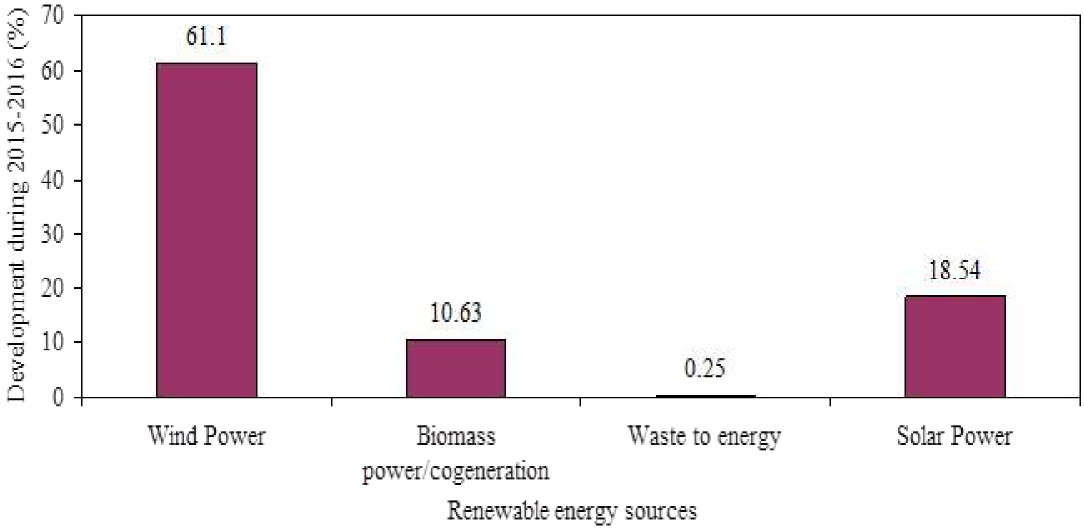

Figure 2. Present Installed capacity of RES in India [1].

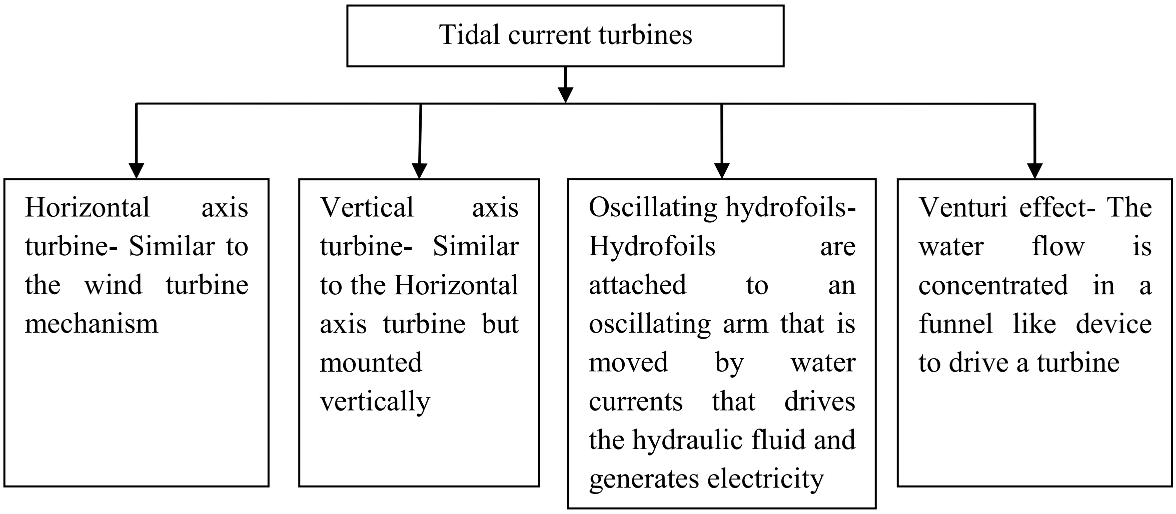

Figure 3. Types of tidal turbines.

Figure 4. High tides (left) and Low tide (right) near a seashore [7].

Harnessing of tidal energy can be implemented either by using the potential energy or kinetic energy of the tides. The tidal barrage technology make use of the potential energy of water by building a barrage in place experiencing tidal range of 5 m or higher whereas the tidal current turbine technology make use of the kinetic energy of the flowing water [10].

At present various countries are going ahead in implementing tidal turbine for energy production. The technically harvestable tidal energy near the coast all around the world is 1TW [11] but due to the high capital cost and maintenance, this technology is preferred only in sites with a potential to produce significant energy. Although tidal energy plant is expensive to carry over, its performance and benefits are proven to be worth in countries like France, UK, China etc [12]. Some of the few tidal energy projects and their power generation capacity around the world are given in table 1.

Approximately there are 20 locations worldwide with significant potential tidal energy and India is one of them. The highest tidal range can be found in Canada at the Bay of Fundy, with a maximum tidal range of up to 16.3 meters [13]. The Gulf of Cambay and the Gulf of Kutch in Gujarat are the places with the highest tidal range in India i.e.,11 m and 8 m respectively. They possess average tidal ranges of about 6.8 m and 5.2 m respectively [14]. These tides brings an average tidal speed ranging between 2.5 m/s to 3 m/s, making tidal turbines a viable option for those sites without the need to build barrages.

3. Tidal Current Turbines

The tidal plants listed in table 1 are only few and many more plants are being developed around the world. For assessing the tidal energy potential in an area, its affecting factors need to be checked. The sea bed should be uniform to minimise turbulence and loss of velocity. The current speed at the site is a major factor responsible for efficient extraction of tidal energy and this can be seen through equation (1) [15].

$$P = 0.5\rho A v^3.C_p \tag{1}$$

Where P is the available power from the water stream, ‘ρ’ denotes the density of water, ‘v’ denotes velocity of the stream, ‘A’ denotes cross section area of the rotor,’Cp’ denotes the coefficient power of turbine and it depends on the design of the turbine. The actuator disk theory show that Cp is limited to below 0.6 for a single stage hydro-kinetic un-shrouded turbine. This the so-called Betz limit. Thus the site resource depends on the current speed, depth and turbine efficiency [16].

This section describes some of the commercially available tidal current technologies that are used for various sites worldwide. However, first we revisit the tidal current turbine classification.

Tidal current devices are typically designed as horizontal or vertical axis turbines for energy extraction. When the tidal currents flow in the direction of axis of rotation of the rotor it is horizontal axis turbine. For structural stability three blades are preferred in most places. The blades are connected with the hub. The hub is connected with shaft. The shaft is the one which is connected with gearbox and a generator. At the rear end of the hub, the generator is placed [17].

The entire setup can be deployed by depending on the seabed arrangement and depth of water. For shallow water region the gravity base, monopile, and pile jacket are considered to be a base structure. The floating type of structures can be used for supporting the assembly in case of larger depth. The design, manufacturing and maintenance of this turbine is simpler than vertical axis turbine. The Horizontal axis tidal current turbine which is commonly called as HATCT, moves slowly and so it should not affect the marine animals [17]. The various HATCT companies around the world and their stage of turbine development are given in detail in the table 2.

In the vertical axis turbine, the flow of tidal currents is in the direction perpendicular to the axis of rotation of the rotor. As the tidal current crosses through the turbine, it is also known as a cross flow turbine. Here it is possible to place the gear box and generator on the floating vessel and the shaft output can be transferred vertically above the sea surface, whereas in horizontal axis turbine it is not possible [17].

However it is complex task to design the vertical axis tidal current turbine (VATCT) and also weighs heavier than the HATCT. Due to the cross flow, the turbine is much prone to cavitation which needs to be driven up. It is not self-starting, generally costlier and having a lower Cp than the HATCT [17]. Still it has been adopted in various sites due to the advantage that it can operate even at low current speed and shallow depth. Another advantage is that VATCT has a simple structure and have straight blades, hence there is no issue regarding direction during the tidal flow changes its direction diurnally [18]. Some of the VATCT projects with their power production capacity at each stage are shown in the table 3 [11].

3.1 Commercially available Tidal turbines that may be suitable for the Indian sector
As discussed earlier, the important factors that affect the tidal energy potential are the current speed and the depth of the site. Minimum of 1 - 2m/s of current speed is required for the turbine to rotate for which the optimum energy can be extracted when the current speed ranges between 1.5 m/s and 3 m/s [18]. A site with 2.5 m/s is considered to have exceptionally high energy resource [19]. However there are also some turbines designed to run at 1m/s and below [19]. The cross-section area of the turbine over which efficient energy can be extracted depends on the water level above the surface of the turbine [16]. The section below describes some of the tidal technologies of different famous companies adopted in various sites all over the world.

3.1.1 SeaGen.

The SeaGen technology has been implemented in 2008 by Marine current Turbine (MCT) which is now a part of the Atlantis resources in UK. The SeaGen technology was developed especially to establish Strangford Lough project. The 1.2MW project of SeaGen technology is the world's first grid connected commercial scale tidal device. So far this technology has generated more than 8GWh of electricity. This MCT uses the experience gained in the Strangford Lough project for further development of the SeaGen technology [20].

The SeaGen marine current turbine technology consists of axial flow rotors which drives a generator through a gearbox. This looks like a wind turbine or a hydroelectric turbine which is as in figure 5.a. The devices are connected to a monopole foundation and are secured to the seabed by a pin-piled quadrapod [20]. The pitch controlled type of rotors is used to minimise the forces on the structure which also optimises the energy extraction. The SeaGen system placed in Strangford lough is shown in figure 5.b in which it has a 20 m rotor diameter is adoptable in marine environment up to 38 m water depth. The rated power of the turbine was found to be achieved when the tidal currents were 2.4 m/s or higher than . Generally maintenance is always an important tedious task for water turbines. Here with the support of the structure, that task is simplified by enabling the turbine to be taken out from the water during maintenance work [21].

Table 1. Some of the Tidal energy projects around the world [22].

Technology	Location	Principle	Rotor size (m)	Capacity (MW)
Tidal Current turbines	Inner sound	Axial-flow		6
Tidal Current turbines	France	Axial-Flow rim type	18	2
Tidal Current turbines	UK	Axial-flow	20	2
Tidal Current turbines	Stangford Lough	Axial-flow		1.2

Tidal Current turbines	Newyork	Axial-flow	5	1.05
Tidal Current turbines	Orkney, Scotland	Axial-flow	18	1
Tidal Current turbines	Ponte Di Archmedia, Strait of Messina	Cross-Flow	6	1
Tidal Current turbines	Norway	Axial-flow	20	0.3
Tidal Current turbines	Maine	Cross-Flow	2.6	0.25
Tidal Barrage	Shiwa lake, South korea			254
Tidal Barrage	LaRance, France			240
Tidal Barrage	Bay of Fundy, Canada			20
Tidal Barrage	Jangxia Creek, East China sea			3.2
Tidal Barrage	The Kislaya tidal facility, Russia			0.4

Table 2. Horizontal axis turbine companies and the stage of development in turbine technology.

Company	**Location**	**Device**	**Stage of Technology**	**Power Capacity**
Atlantis Resources Corporation	UK	Nereus	Scale model sea trials	150 kW
Clean Current Power Systems	Canada	Clean Current tidal turbine generator	Full scale prototype	65 kW
Free Flow Power	Gloucester, MA	Smart Turbine Generator	Scale model tank testing	10 kW
Free Flow 69	UK	Osprey	Scale model sea trials	1 kW
Hammerfest Strom UK	UK	Tidal Stream Turbine	Full scale prototype	300 kW
HydroCoil Power, Inc.	Wynnewood, PA	HydroCoil	Scale model sea trials	20–40 kW
Hydro Green Energy	Huston, TX	Hydro+	Commercial	35 kW
Maine Current Turbines	UK	SeaGen	Full scale prototype	300 kW–1.2 MW
Natural Currents Energy Services	Highland, NY	RED HAWK Tidal Turbine	Scale model sea trials	125 kW
Ocean Flow Energy	UK	Evopod	Scale model sea trials	1 kW
Ocean Renewable Power Company	Fall River, MA	ORPC Turbine Generating Unit	Scale model sea trials	32 kW
OpenHydro	Ireland	Open-Centre Turbine	Full scale prototype	250 kW–1 MW

Robert Gordonz University	UK	Sea Snail	Full scale prototype	150 kW
SMD Hydrovision	UK	Tidal	Scale model tank testing	500 kW
Swan turbine Ltd.	UK	Swanturbine	Scale model sea trials	330 kW
Tidal Energy Pty. Ltd.	Australia	Davidson-Hill Venturi Turbine	Scale model sea trials	Unavailable
Tidal Generation Ltd.	UK	DEEP-Gen	Full scale prototype	500 kW
Tidal Steam	UK	Triton	Scale model tank testing	10 MW
Tocardo Tidal Energy Ltd.	Netherlands	Tocardo Aqua 2800	Full scale prototype	32 kW
University of Strathclyde	UK	Contra-Rotating Marine Turbine(CoRMaT)	Scale model sea trials	30 kW
Verdant Power	New York, NY	Free Flow System	Full scale prototype	35 kW–1 MW

Table 3. Vertical axis turbine companies and the stage of development in the turbine technologies.

Company	Location	Device	Stage of Technology	Capacity (kW)
Blue Energy	Canada	Blue Energy Ocean Turbine	Scale model sea trials	250
C-Energy	Netherlands	Wave Rotor	Scale model sea trials	30
Lucid Energy Technologies LLP	Goshen, IN	Gorlov Helical Turbine	Scale model sea trials	20
New Energy Corporation Inc.	Canada	EnCurrent Turbine	Full scale prototype	5–250
Ponte di Archimede International S.P.A.	Italy	Enermar	Scale model sea trials	25
Sea Power International AB	Sweden	EXIM	Scale model sea trials	48–72

3.1.2 Andritz Hydro Hammerfest.

The Andritz Hydro Hammerfest tidal turbines is a UK based company which are suitable for sites with low current speed of even 1 m/s. Those sites in associated with water having depth between 35 m to 100 m can adopt this turbine. It has the rated power of 500 - 2000 kW. The rotor with three blades open has a swept area of 300 -500 m^2. This horizontal axis turbine has specially designed pitching system which enables the turbine to harness the tidal energy both in ebb and flood directions. The nascelle of the turbine is designed in such a way that it minimises the wake effects that hinders the optimum energy extraction. The unique installation methodologies in this system minimise the installation time and needs only Remotely Operated Vehicles (ROV) for maintenance [23]. The picture of the Andritz Hammerfest turbine is shown in the figure 6.

The two important prototypes that Andritz Hydro Hammerfest developed are HS300 and HS1000.

3.1.2.1 HS300: The HS300, the first prototype of Andritz Hydro Hammerfest is in Norway. It was operated from 2003 – 2007 and reinstalled for the period from 2009 – 2011. The turbine was installed at 50 meters water depth which has the production capacity over 600MWh per year. The continuous long time operation of this turbine proved it to be efficient and reliable [6]

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3.1.2.2 HS1000: After the successful installation of the 300 kW tidal energy project in Norway, a 1 MW device named HS1000 was developed, tested and installed in December 2011 in cooperation with the Scottish power renewables [6]. HS1000 is the first ever pre-commercial tidal turbine to validate the technology for the world's first tidal power array system at the Europen Marine Energy Center (EMEC), Orkney, Scotland [24]. The device was connected to the grid by February 2012 and has the production capacity of about 3.1GWh per year and satisfies the need of over 500 houses [6].

3.1.3 Atlantis Orkney, UK.
AR1000 of Atlantis Resource is the world's most powerful single rotor tidal turbine company from UK. Its rated capacity is 1MW when the current speed is 2.65 m/s. The 18 m diameter of rotor makes the turbine as one of the largest tidal turbine ever built with 22.5 m height and 1500 tonnes of weight. The two sets of blades fitted on the single unit tackles the fluxea and flood tides. This featured tidal turbine was installed in Orkney, UK in August 2011 and it is shown in the figure 7 [25].

3.1.4 MeyGen.
Meygen is the world's largest tidal stream project currently under construction [26]. Meygen is 85% owned by the Atlantis Resources solely for the development of the inner sound tidal site. [26]. For the first phase of the project they have two turbine suppliers, Atlantis Resources Ltd and Andritz Hydro Hammerfest [26].

They use the turbine AR1500 device from Atlantis Resources Ltd. Its rated capacity is 1.5 MW at 3 m/s. The turbine has 360 degree yawing capacity and active pitch blades that yields maximum energy. The deployment and connection work is made easy and can be done in 90 minutes [25].

HS1500 of Andritz Hydro Hammerfest has the same features as of HS1000 but with rated capacity of 1.5 MW. The rated capacity is achieved at a current speed of 3 m/s. A sensor driven monitoring system governed by an automatic control software adjust the leading edge to extract optimum output from the tidal currents [25]. For initial development of the project, 1 X AR1500 and 3 X HS1500 devices have been selected that will provide overall capacity of 6 MW which will grow upto 400 MW in the later phase. The turbines will be given a gravity based mooring system [27].

3.1.5 Ponte Di Archmedia, Strait of Messina: Ponte di Archimede International S.p.A was established as a part of the Caronte Shipping Group in 1983. Their main projects is on re-newable energy and a submerged floating tunnel. They were involved in the marine hydro projects at Straight of Jintang and Straight of Messina in China [28].

They use the cross flow turbines named as Enermor Kobold turbine for harnessing energy from the currents. It is a three bladded turbine with the length of 5 to 6 m and rotor diameter of about 6 m. The Enermor Kobold turbine is a uni-directional vertical axis turbine with a high starting torque and provides spontaneous start, so it avoids the purpose of ignition system to start even in worse condition [29]. The picture of this turbine is shown in the figure 8.

The Enermor project located in Strait of Messina along the Sicilian coast was installed in a depth of 18-25 m in 2001. The designed power capacity is 80 kW and produces 25 kW in the place with 2 m/s current speed [30]. Table 4 provides the detail on the tidal turbines, type of the turbines with its rated capacity at different current speed.

4. Tidal Turbine Technologies for Indian sites

India is one of the few tidal energy potential sites in the world which is covered by ocean on three sides. This enables the ocean to attain high tidal range at some places. The potential sites in India are shown in the figure 9 [22].

In India places like Gujarat and Sundarbans were already found to have a significant tidal potential sometime ago. A study made by Indian Institute of Technology- Madras reveals the distribution of current speed along the Indian coast lines, which are listed in table 5 [11]. Based on the

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available data about the current speed the probable type of turbine that can be adopted for Indian sites are suggested further.

The Gulf of Khambat is one of the richest locations of tidal energy potential in India. It experiences a tidal range of 5 to 11 m. The site has a typical current speed of 2.5m/s and an average potential energy of 10.9MW/km^2 and kinetic power of the tidal current of about 4000W/m^2. per cross-section area of the turbine. Among the above discussed turbines in Section 3; SeaGen, Andritz Hydro Hammerfest, and Enermor Kobold turbines can be suitable in places with a current speed below 2.5m/s. The Gulf of Kutch having 4 to 9m tidal range is the location with the highest current speed of 3m/s. The average potential energy available is 7.2MW/km^2 and average kinetic power of about 4500W/m^2 per cross-section area. Any of the turbines discussed in the above section can be used in places where the current speed is less than 3m/s.

Sundarbans with a tidal range of 4 to 7m is another important tidal energy potential site in India that has current speeds of 2 to 3m/s. The average potential energy available in this location is 7.2MW/km^2 with an averaged kinetic power of about 4000W/m^2 per cross-section area. Since the current speed varies between 2 to 3m/s, it is always safer to prefer the turbine for lower condition which can produce electricity even below 2m/s. In this approach the Andritz Hydro Hammerfest and Enermor Kobold turbines may be suitable for this location. South of Gujarat has a tidal range of 2 - 4m and current speed of 2m/s. The average available potential energy is 1.5 MW/km^2 and an averaged kinetic power of about 4000W/m^2 per cross-section area. For this again, the Andritz Hydro Hammerfest and Enermor Kobold turbines may be suitable.

All other places like Maharastra, Karnataka, Kerala, and Orissa have a low current speed of 1.5m/s while Andhra has a minimum of 1m/s for which the turbines from Andritz Hydro Hammerfest can be suitable for those locations. Table 6 gives an overview on the preferable tidal turbine technologies for various Indian sites with respect to the available current speed and water depth

Figure.5

Figure.5

Figure.6

Figure 5.a) The SeaGen system full view [31]. **b)** The SeaGen system adopted in Strangford lough, UK [31].

Figure 6. Andritz Hydro Hammerfest tidal turbine [23].

Figure 7. Enermor Kobald turbine [30] .

Figure 8. Atlantis AR1000 Tidal turbine [32].

Table 4. Information about tidal turbine.

Company name	**Type of Turbine**	**Working Current Speed**	**Installation Depth**	**Rated capacity**
SeaGen	Horizontal axis turbine	2.4 m/s	38 m	500- 2000 kW
Andritz Hydro Hammerfest	Horizontal axis turbine	Even below 1m/s	35- 100 m	HS 300- 600MWh HS1000- 3.1GWh
Atlantis	Horizontal axis turbine	2.65 m/s	NA	1MW
MayGen	Horizontal axis turbine	Atlantis- 3 m/s Andritz Hydro hammerfest- 1 to 4 m/s	NA Below 100m	1.5 MW
Enermor Kobold Turbine	Vertical axis turbine	2 m/s	12- 25m	80 kW

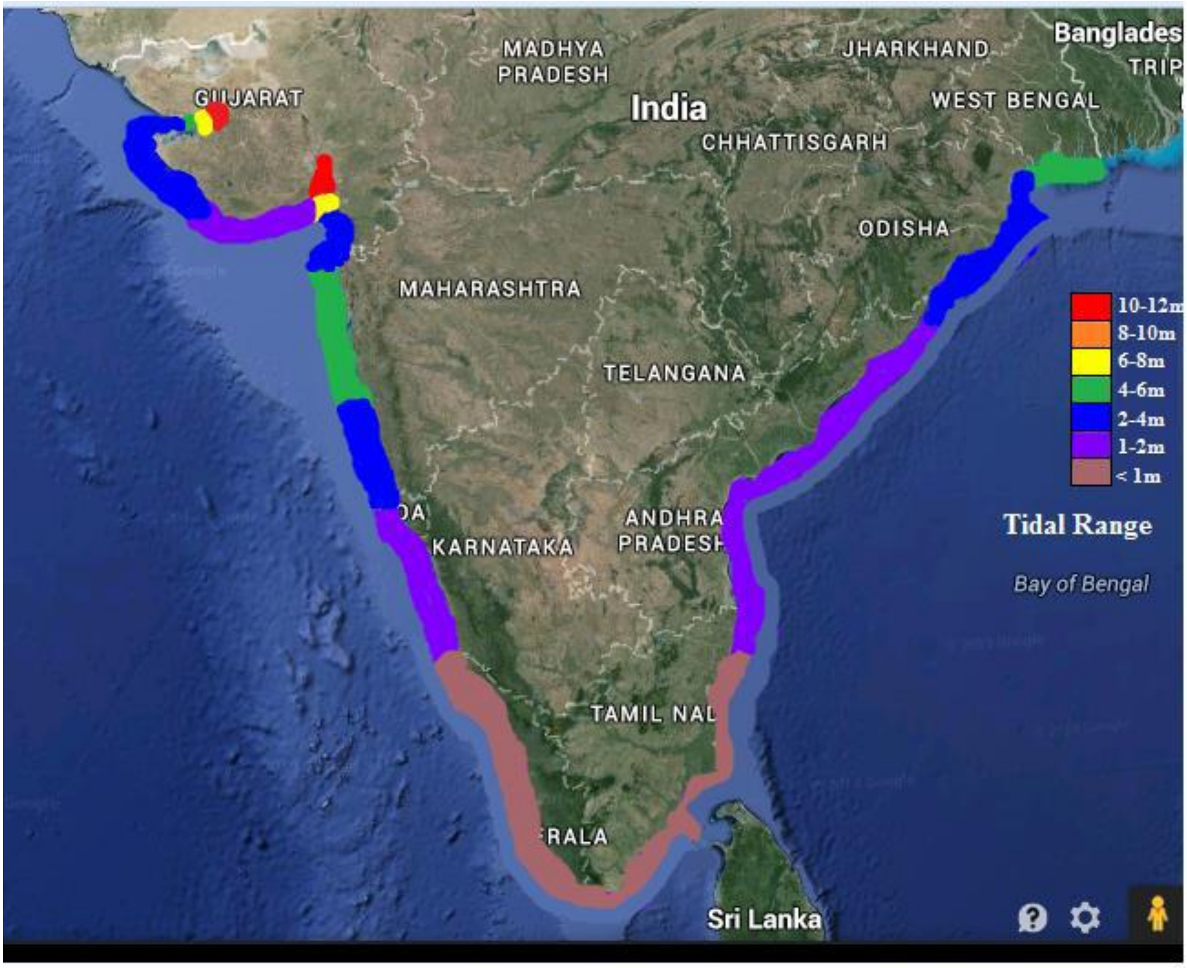

Figure 9. Tidal energy potential along Indian coast [22].

Table 5. Site characteristics along various coasts of India [22].

Coastal Region	Tidal range (m)	Typical tidal current, m/s	Ave. Available PE per sq. km (MW)	Ave. Available KE per m^2 (W)
Khambat	5-11	2.5	10.9	2604.3
Kutch	4-9	3.0 m/s	7.2	4500.2
South Gujarat	2-4	2.0 m/s	1.5	1333.4
Maharashtra	2-4	1.5 m/s	1.5	562.5
Karnataka	1-1.5	1.5 m/s	0.2	562.5
Kerala	1-1.5	1.5 m/s	0.2	562.5
Tamilnadu coast	1	0.8 m/s	0.1	85.3
Andhra coast	1-2	1.0 m/s	0.2	166.7
Orissa coast	2-4	1.5 m/s	1.5	562.5
Sundarbans	4-7	2-3 m/s	7.2	2604.3

Table 6. Tidal Technologies for Indian sites.

Coastal Region	Typical Tidal Current	Type of Turbine Suggested	Type of Turbine may be suitable	Technical Specifications
Khambat	2.5m/s	Horizontal / vertical axis turbine	Andritz Hydro Hammerfest, Enermor Kobold	**Andritz Hydro Hammerfest** 11.5m pivoting blades, Functional water speed: 1 to over 4 m/s Water depth: 50-100m No of blades: 3 22m tall tripod base Rotor swept area: 300-500 m^2 Generator type:Induction Nominal Output: 500- 2000 kW Rotation per minute: 7-10 [33] **Enermor Kobold** Rotor diameter: 6m Number of blades: 3 Blade span: 5m Functional water speed: 1.8m/s to 3m/s Attached on a steel platform having 10 m diameter thereby moored to the seabed by using four mooring lines [34]
Kutch	3.0m/s	Horizontal / vertical axis turbine	SeaGen, Andritz Hydro Hamerfest, Atlantis-MeyGen, Enermor Kobold	**Andritz Hydro Hammerfest** 11.5m pivoting blades, Water depth: 50-100m Functional water speed: 1 to over 4 m/s 22m tall tripod base No of blades: 3 Rotor swept area: 300-500 m^2 Generator type:Induction Nominal Output: 500- 2000 kW Rotation per minute: 7-10 [33] **Atlantis- MeyGen (Atlantis - AR1500 & Andritz HS1000)** Atlantis - AR1500 1.5MW nameplate capacity Rated at 3 m/s Variable pitch Electric yaw Wet mate connection Andritz Hydro Hammerfest -

				HS1000 • 1.5MW nameplate capacity • Rated at 3.15 m/s • Variable pitch • Hydraulic yaw • Dry mate connection [35] **Enermor Kobold** Rotor diameter: 6m Number of blades: 3 Blade span: 5m Functional water speed: 1.8m/s to 3m/s Attached on steel platform having 10 m diameter thereby moored to the seabed by using four mooring lines [34]
South Gujarat	2.0m/s	Horizontal / vertical axis turbine	Andritz Hydro Hammerfest and Enermor Kobold	**Andritz Hydro Hammerfest** 11.5m pivoting blades, 22m tall tripod base Water depth: 50-100m Functional water speed: 1 to over 4 m/s No of blades: 3 Rotor swept area: 300-500 m^2 Generator type:Induction Nominal Output: 500- 2000 kW Rotation per minute: 7-10 [33] **Enermor Kobold** Rotor diameter: 6m Number of blades: 3 Blade span: 5m Functional water speed: 1.8m/s to 3m/s Attached on steel platform having 10 m diameter thereby moored to the seabed by using four mooring lines [34]
Maharashtra	1.5m/s	Horizontal axis turbine	Andritz Hydro Hammerfest	**Andritz Hydro Hammerfest** 11.5m pivoting blades, 22m tall tripod base Water depth: 50-100m Functional water speed: 1 to over 4 m/s No of blades: 3 Rotor swept area: 300-500 m^2 Generator type:Induction Nominal Output: 500- 2000

				kW Rotation per minute: 7-10 [33]
Karnataka	1.5m/s	Horizontal axis turbine	Andritz Hydro Hammerfest	**Andritz Hydro Hammerfest** 11.5m pivoting blades, 22m tall tripod base Water depth: 50-100m Functional water speed: 1 to over 4 m/s No of blades: 3 Rotor swept area: 300-500 m^2 Generator type:Induction Nominal Output: 500- 2000 kW Rotation per minute: 7-10 [33]
Kerala	1.5m/s	Horizontal axis turbine	Andritz Hydro Hammerfest	**Andritz Hydro Hammerfest** 11.5m pivoting blades, Functional water speed: 1 to over 4 m/s No of blades: 3 22m tall tripod base Rotor swept area: 300-500 m^2 Generator type:Induction Nominal Output: 500- 2000 kW Rotation per minute: 7-10 [33] Water depth: 50-100m
Andhra coast	1m/s	Horizontal axis turbine	Andritz Hydro Hammerfest	**Andritz Hydro Hammerfest** 11.5m pivoting blades, Functional water speed: 1 to over 4 m/s 22m tall tripod base No of blades: 3 Rotor swept area: 300-500 m^2 Generator type:Induction Nominal Output: 500- 2000 kW Rotation per minute: 7-10 [33] Water depth: 50-100m
Orissa coast	1.5m/s	Horizontal axis turbine	Andritz Hydro Hammerfest	**Andritz Hydro Hammerfest** 11.5m pivoting blades, Functional water speed: 1 to over 4 m/s 22m tall tripod base No of blades: 3 Rotor swept area: 300-500 m^2 Generator type:Induction Nominal Output: 500- 2000 kW Rotation per minute: 7-10 [33] Water depth: 50-100m
Sundarbans	2-3m/s	Horizontal /	Andritz Hydro	**Andritz Hydro Hammerfest**

Vertical axis turbine	Hammerfest and Enermor Kobold	11.5m pivoting blades, Functional water speed: 1 to over 4 m/s 22m tall tripod base No of blades: 3 Rotor swept area: 300-500 m^2 Generator type:Induction Nominal Output: 500- 2000 kW Rotation per minute: 7-10 Water depth: 50-100m [33] **Enermor Kobold** Rotor diameter: 6m Number of blades: 3 Blade span: 5m Functional water speed: 1.8m/s to 3m/s Attached on a steel platform having 10 m diameter thereby moored to the seabed by using four mooring lines [34]

5.Conclusion

Marine energy and particularly tidal energy have a significant potential worldwide and in India as well to become a reliable renewable energy source. This study focused on the availability of the tidal energy source and especially the tidal current source as a viable option for the Indian energy sector. The fundamental aspects of tidal energy generation have been discussed, followed by descriptions of current tidal energy projects worldwide and the type of tidal current turbines used for those projects. From those types, potential turbines were selected for sites identified along the Indian coast, having a good level of tidal energy. Parameters as current speed and water depth were crucial in determining the type of turbine that can be used for the particular Indian site. Although there was some variation between the turbines in terms of their suitability to the site, generally speaking, it was found that the Horizontal axis turbines of Andritz Hydro Hammerfest are suitable for most of the Indian Sites and the Vertical axis turbine from Enermor Kobold can be used for types, potential turbines were selected for sites identified along the Indian coast, having a good level of tidal energy. Parameters as current speed and water depth were crucial in determining the type of turbine that can be used for the particular Indian site. Although there was some variation between the turbines in terms of their suitability to the site, generally speaking, it was found that the Horizontal axis turbines of Andritz Hydro Hammerfest are suitable for most of the Indian Sites and the Vertical axis turbine from Enermor Kobold can be used for sites as Gujarat and Sundarbans having appropriate water depth and current speeds.

Identifying the sites and the type of applicable tidal turbine is the first step towards designing an installation. Each site is different in its challenges and thus local adaptation of the design is required. This includes consideration of water surface waves on the tidal turbine performance in case of shallow water as relative to the turbine length scale [36], hydrodynamic optimization of the turbine to the local conditions of current speed [37], optimized control design to achieve maximum power output [38] and efficient power transmission to the shore. These are some of the challenges that are faced the sector in which this research group and others are working.

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