Recent Developments of Tidal Energy as Renewable Energy: An Overview

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1 Introduction

Marine energy also known as ocean energy is one of the main source of renewable energy as approximately 70% of the earth's surface is surrounded by it. It possess large amount of energies in the form of tidal energy, tidal currents, wave energy, temperature gradient and salinity gradient which are sufficient enough to meet the global energy demand. The tides and ocean waves consist of kinetic and potential energy which can drive the turbine to produce power. Similarly salinity gradient and temperature gradient within the bodies of ocean create dynamic forces that can also be exploited to generate electricity as well as to get fresh water.

Currently, a lot of research and studies are going on globally to identify the feasible areas, technologies needed to trap such energies, cost of generation and environmental impact assessment of such proposed technologies.

India is having advantageous position in respect of harnessing the ocean energy as it has a 7500 km long coastline and is surrounded by sea on three sides. Also it consists of 336 Islands in the Bay of Bengal and Arabian Sea (Afd 2014). Further being a tropical country, large temperature difference exists between surface and deep water which can also be utilized to produce electricity and fresh water. Government of India recognized these potentials and recently a lot of initiatives have been taken to extract such forms of energy. Govt. of India Ministry of New and Renewable Energy (MNRE) has proposed a plan to finance as much as 50% of the cost of projects working in these areas. Department of Ocean, IIT Madras and National Institute of Ocean Technology (NIOT) are doing a lot of research to access the potentials available and harnessing potentials, site selection, technology to be adopted, cost of generation and environmental impact analysis.

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2 Tidal Energy

Tidal energy is one of the most promising, predictable and reliable form of ocean energy which does not emit carbon dioxide or produce any waste. Tides in the ocean as shown in Fig. 1 are due to naturally occurring gravitational pull of the sun and moon which causes the cyclic rise and fall in the level of seas, usually every 12 h interval.

When the gravity of moon and earth is in the same line, the influence of gravitational pull becomes so strong that large quantity of seawater starts to flow towards the seashore, thus producing a condition known as high tide. During this, the water level reaches its highest level from the mean sea level. Similarly when the gravity of moon and earth is at 90° to each other, the influence of gravitational pull becomes so weak that the seawater starts to flow away from the seashore and moves towards other location of earth. This condition is known as low tide and water is at a lowest level.

The difference of elevation between high and low tides is called tidal range which depends upon the position, depth and shape of the coastline. This process happens twice a day. The number of tide per day is dependent on the declination of moon′s orbital plane relative to the axis of rotation of earth. In most part of oceans in the world, two tides occur in a day which is called as semi diurnal which is the most dominant pattern. There are 29 locations (Afd 2014) where only one tide occurs in a day which is known as diurnal. These types of tides occur in the Gulf of Mexico (along the northern shore)—Atlantic Ocean, Gulf of Tonkin—northern arm of South China Sea and Java Sea—Sunda Shelf of Java Island. Some tides combine the characteristics of both diurnal and semidiurnal tides, known as mixed tides. In this case tides are usually semidiurnal but occasionally the tides become diurnal and large inequality exists in high water height, low water height or both. It is more common along the Pacific coast of USA.

Depending upon the respective location of sun, moon and, earth; the amplitude of tides vary. When, these are aligned collinear during the full and new moon phase, the gravitational pulls are added up during each tidal cycle to produce highest and

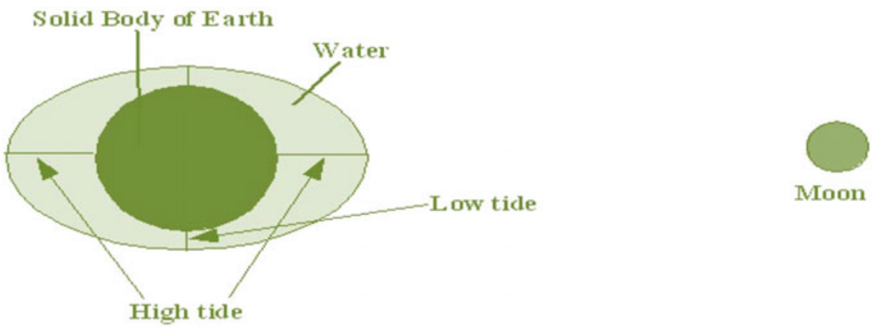

Fig. 1 High and low tide (Afd 2014)

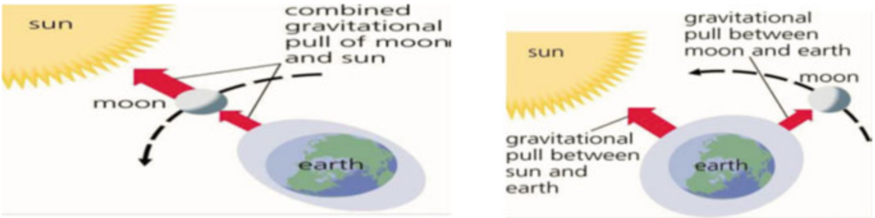

Fig. 2 Spring and neap tides (Afd 2014)

lowest tides. It is called as spring tides. Similarly when these are aligned at right angles during quarter moon phase, the tides are not so high or low. These weak tides are known as neap tides. Both these have been shown in Fig. 2.

Tidal range is the potential energy which can be harnessed to generate electricity. The exploitation of energy is very much depended upon the site as to get sufficient power, it is necessary that the tidal range should be more than 5 m. Approximately 20 locations (Adf 2014) are available on the earth′s surface which has more than 5 m tidal range. It also includes India. It is highly predictable and is hardly influenced by weather conditions and the energy can be harnessed throughout the day including night times. Maximum power is generated during spring tide while neap tide produces minimum power.

Further tidal currents which contains large amount of kinetic energy, can also be harnessed to generate power. The weather conditions affect it slightly but in the long run, the fluctuations are small. As the plants are under water, land infrastructure requirements are low and also in some cases, it may be integrated with the existing structures. For tidal stream plant, the depth of water should be more than 35 m and it requires flow velocity more than 3 m/s (Afd 2014).

2.1 Technology

There are two different ways by which tidal energy can be harnessed. One is to utilize the cyclic rise and fall of tides using barrage, known as tidal barrage method and other is to utilize the tidal currents due to movement of sea water which are similar to wind power, popularly known as marine current method. The details of these methods have been discussed below:

2.1.1 Tidal Barrage Method

This method utilizes the potential energy of tidal range by strategically positioning the dam. This system resembles the hydroelectric power generation through dam except that the dam is much bigger and spans across the full width of bay or estuary.

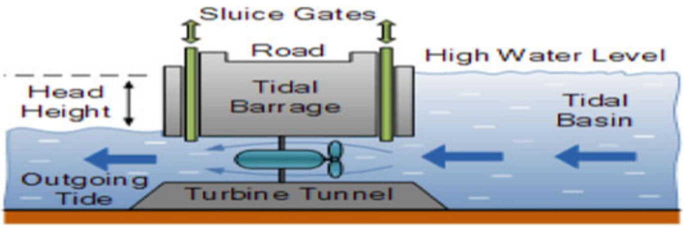

Fig. 3 Tidal barrage

As the water level of sea changes during tides, a difference of head is created across the barrage as shown in Fig. 3.

The flood tide i.e. allowing the reservoir to fill up with water through sluice gates; the ebb tide i.e. receding of water or both can be used to run the turbine which in turn produces electricity.

The potential energy P over a tidal cycle can be given as

$$P = \frac{1}{2}\rho g A(\Delta h)^2$$

where, ρ = sea water mass density in t/m^3, g = acceleration (due to gravity) in m/sec^2, A = enclosed horizontal area of the basin in Km^2 and Δh = basin mean tidal range in m.

A number of options are available for generation of power which has been discussed below:

(a) **Power Generation During Ebb Tide**

In this case, during flood tide, the reservoir is allowed to fill up with water through sluice gates and the same is closed as tides have reached its highest level. During ebb tides, water is released from the reservoir to drive the large turbines which generate power. Through this system, power can be generated only for 4 h per day.

Annapolis Royal Generation Plant located in Canada, is an ebb generation plant. It is producing 20 MW power. It was commissioned in 1984 by Nova Scotia Department of Energy Canada. It is the only tidal plant in North America. Annual generation of the plant is 50 GWh.

(b) **Power Generation During Flood Tide**

In this case, during flood tide, the sluice gates are closed and water from the sea is allowed to flow into reservoir through large turbines which generate power. This system has disadvantages that it has less capacity to generate power and also for longer period, the reservoir′s water level is kept at low level.

Sihwa Lake Tidal power station (South Korea) is a flood generation type plant. It is world′s largest tidal power station producing 254 MW and is operated by the Korea Water Resource Corporation. It was commissioned in 2011 and started to operate in

2012. The average tidal range at the station is around 5.6 m with a 7.8 m spring tidal range. The annual plant generation is of 552.7 GWh with capacity factor 24.8%.

(c) **Power Generation During both Flood and Ebb Tide**

In this case, both flood and ebb tides are utilized for generation of electricity through reversible turbines, operating both in and out direction. Through this system, power can be generated twice daily for 4 h.

Rance Tidal Power Station (located on the estuary of Rance River in Brittany, France), is a flood and ebb generation plant. It is the oldest and second largest plant in terms of installed capacity. It is operating since 1966 and generates 240 MW through 24 bulb type turbines of dia 5.4 m, rated at 10 MW and weighing 470 tonnes each. Currently, it is operated by Electrcite de France (EdF). The annual output of the plant is of approximately 600 GWh with capacity factor 28%. The average tidal range at the station is 8.2 m with maximum value of 13.2 m. The use of bulb type turbine allows the generation of power during both flood and ebb tide. Cathodic protection is used for all turbines, gates and locks. Hence, after 40 years of operation, none of the turbine blades have required any replacement.

Current Status

Currently tidal range plant capacity of 521 MW already exists and 1.7 GW is under progress and in construction phase. The various major projects which are at present operational, are given in Table 1.

Presently two large tidal plants are under construction, Incheon Tidal Power Plant of 1.3 GW and Saemangeum Reclamation Project of 0.4 GW, both located in South Korea on Yellow Sea. According to World Energy Council 2016 Report, approximately 13.7 GW project is under deployment and 0.7 GW has received consent in East China Sea, South Korea and Kenai Peninsula USA. Further, the status of other projects are: non-consented but in pipeline—10.7 GW, in planning stage—0.32 GW, early planning stage—2.8 GW and at conceptual stage—7.6 GW. All these are shown in Fig. 4.

Development in India

India has a huge potential of harnessing tidal energy as it has a 7500 km long coastline covering all along its three sides. The study of tide level at various locations along the coastline has been done by IIT Madras and National Institute of Oceanography. From the study, it has been observed that the most attractive locations in India are

Table 1 Tidal Power Plant in operation (Afd 2014)

Name of the project	Capacity (MW)
Sihwa Lake Tidal Plant (South Korea)	254
Rance Tidal Plant (France)	240
Annapolis Royal Tidal Plant (Canada)	20
The Jiangxia Tidal Plant (China)	3.2
The Kislaya Guba Tidal Plant (Russia)	0.4

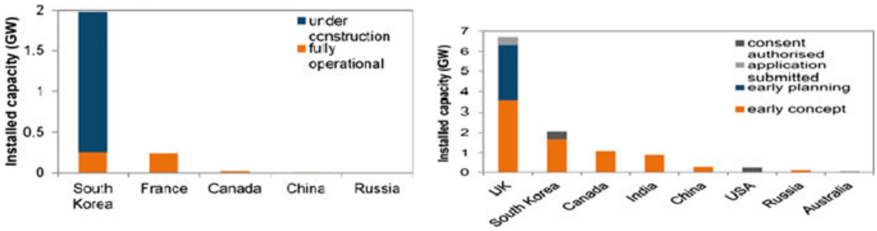

Fig. 4 Status of tidal range plant capacity in operation/under construction/progress

on the west coast—Gulf of Khambat and Gulf of Kutch and along the Sunderbans Ganges Delta areas of West Bengal. In the Table 2, the current estimate of gross potential of each site is given below.

The State-wise potential is also estimated which is given in Table 3.

Table 2 Potential assessment of tidal range power (Afd 2014)

Region	Site condition	Potential option	Current gross assessment (MW)
Gulf of Khambat	Depth—12–15 m Tidal Range—11 m	Barrage	7000
Palk Bay—Mannar Channel	Depth—60 m Tidal Range—1 m Four times a day	Barrage	230
Hoogly River	Depth—6 m Tidal Range—4–6 m	Barrage	900

Table 3 Potential of Tidal Range Power State-wise (Afd 2014)

State	Tidal range (m)	Technology	Tidal range power potential (MW)
Gujarat	5–11	Tidal Barrage	7000
Maharashtra	2–4	Tidal Barrage	200
Karnataka	1–1.5	Tidal Barrage	100
Kerala	1–1.5	Tidal Barrage	100
Tamil Nadu	0.8–1.0	Tidal Barrage	230
Andhra Pradesh	1–2	Tidal Barrage	100
West Bengal	4–6	Tidal Barrage	900
Orissa	2–4	Tidal Barrage	400

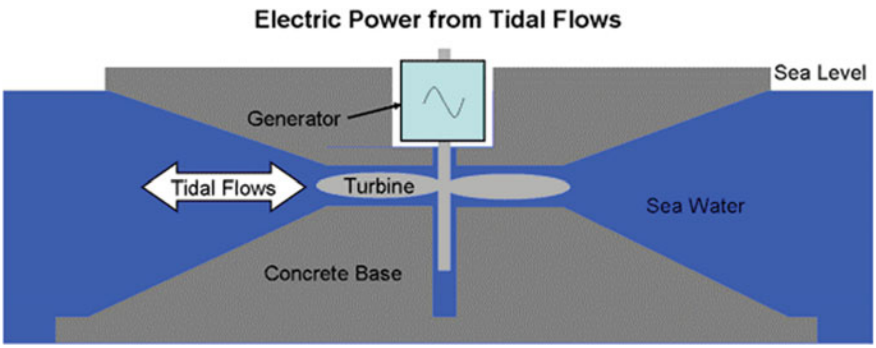

Fig. 5 Development of power through tidal currents

2.1.2 Marine Current or Tidal Current

The horizontal movement of water during tides which flows in and out of estuaries possesses enormous kinetic energy, generally known as tidal stream current. This kinetic energy can be harnessed to generate power which depends upon the velocity of flowing stream and the area intercepted. It generates power during both flood and ebb tides as shown in Fig. 5.

The power developed by this system can be expressed as:

$$P = C_P \frac{1}{2} \rho A V^3$$

where, P = power generated, C_P = coefficient of turbine power, ρ = sea water mass density, A = turbine swap area and V = flow velocity.

Tidal steam plants operate below the surface of sea or are mounted/fixed to sea bed. Various different types of devices exist which have been described below in detail:

(a) **Horizontal Axis Turbine**

In horizontal axis turbine, blades rotate about an axis parallel to the direction of water flow and sweeps through a circular area. It has 2–3 blades mounted on the rotor and lift type blades are usually employed to increase the power output. It requires specially shaped airfoil surface which creates pressure difference between the two sides of the blade. This develops a net force in the direction perpendicular to the water flow that drives the turbine. These are the most common and popular type of tidal plant developed. Approximately 76% of all tidal stream plants are horizontal axis turbine.

SeaGen device developed by Marine Current Turbines Ltd. UK which was undergoing full size prototype testing since April 2008 in Stangford Lough (Northern Ireland), is the first commercial scale device that started full power generation of 1.2 MW in December 2008. In July 2008, for the first time, it had fed 150 KW into the grid. It has been designed for a life period of 20 years. Currently, it is the only device installed anywhere in the world at the commercial scale.

(b) **Vertical Axis Turbine**

In vertical axis turbine, the method of extraction of energy is same as that of horizontal one except here, the axis of rotation of the rotor is vertical to the water surface and also perpendicular to the incoming flow. It employs either lift type or drag type blade and also in some design using a combination of both. Approximately 12% tidal stream plants are of vertical axis turbine type.

The Kobold tidal turbine is a vertical axis turbine using the lift force to generate power. It is developed by Italian National Institute for Naval Architecture Studies and Testing (ISEAN), Italy and Ponte di Archimede International S.p.A. Messina, Italy. Its concept was started in 1995 and in 2001; a pilot plant was installed 150 m offshore near Messina. The current at the site was in between 1.5–2 m/s and at some location it was more than 3 m/s. The turbine was having 3 blades of 6 m diameter. When deployed, the turbine produced 25–30 KW. In 2005, it was connected to electric grid and a submarine cable was used to connect the turbine to the land based electrical grid.

(c) **Venturi type Device**

This type of device uses a shroud which increases the flow velocity through the turbine and it also aligns the current. Hence, for a given power output, a smaller diameter of the turbine is required. It can be placed both horizontally or vertically.

In 2002, Tidal Energy Pvt. Ltd, an Australian Company on the Gold Coast, Queensland; had undertaken the commercial trails of highly efficient shrouded turbines very successfully. It had also developed the shrouded turbine in the remote area of the Northern Australia where the current velocity was recorded as high as 11 m/s.

All the above three have been shown in Fig. 6.

(d) **Oscillating Hydrofoils**

This type of device consists of airplane wings shaped blades called hydrofoils placed at the end of a swinging arm as shown in Fig. 7. As the tidal stream flows on either side of blade, the hydrofoil moves up and down that generates lift perpendicular to the flow causing the liver to rise. These oscillating movements drive the water in a

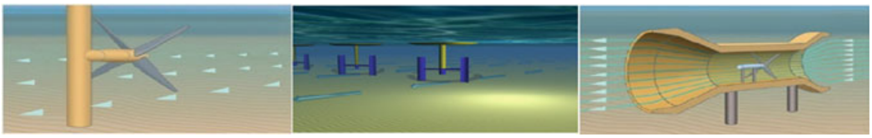

Fig. 6 Horizontal axis, vertical axis and Venturi type device

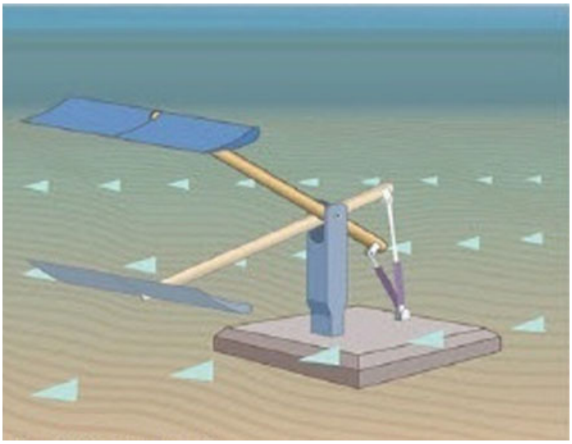

Fig. 7 Oscillating hydrofoils

hydraulic system to generate power. The advantage of this system is that the blade length is not restricted by the depth of water.

In 2014, Pulse has developed an oscillating hydrofoil tidal plant in the Humber Estuary in which tidal streams cause the horizontal blade to move up and down to drive the turbine. A 100 KW trail rig fed power in a chemical company situated on the bank of river. On successful demonstration of its technology, they are planning to develop a 1.2 MW plant for commercial deployment named as PS1200.

(e) **Tidal Kites**

Minesto′s Deep Green Concept has given a new technology to generate power in a stream which flows at a low speed between 1.2–2.4 m/s and depth of sea between 60 and 120 m. The basic principle on which this turbine operates is similar to flying kite along the sea beach. The hydrodynamic lift force on the wing is produced by the underwater flowing current which lifts the wing (kite) upwards into an eight shaped trajectory as shown in Fig. 8. The water flows through the turbine as the kite flies in the flowing current, which in turn produces power. The power plant consists of a wing which carries turbines directly coupled to generator.

Till date five prototypes based on this concept have been tested and first time electricity was produced in 2009. The first commercial scale plant of 0.5 MW has been installed in Holyhead Deep in Wales.

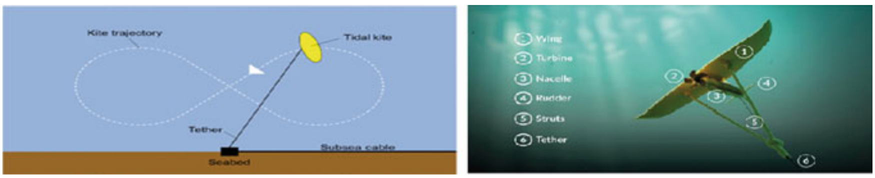

Fig. 8 Operation and components of tidal kite

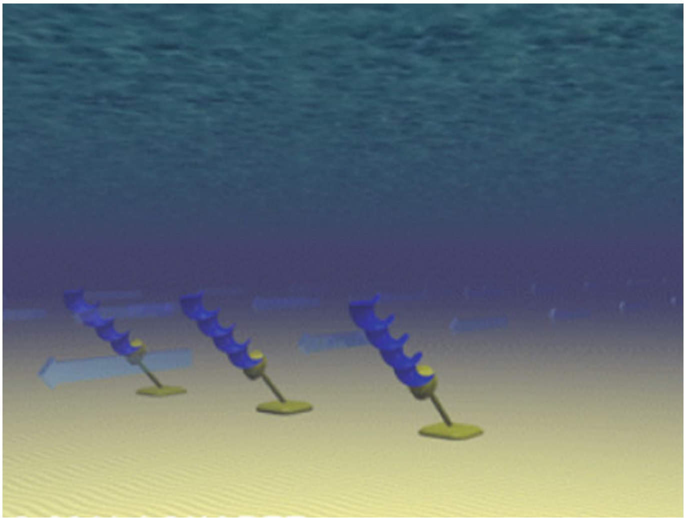

Fig. 9 Archimedes helical screw

(f) **Archimedes Tidal Screw**

It is a helical corkscrew shaped device consisting of a helical surface that surrounds a central cylindrical shaft. It extracts power from the tidal stream when the water moves up or through the spiral which in turn drives the turbine as shown in Fig. 9.

Current Status

The potential area of tidal current is located in the areas where there is a high tidal range. However, increased potential has been observed in areas where the flow of water is obstructed or constrained by local topography like headlands, narrow straits etc. and also where there is a relatively shallow water depth. It is very difficult to get the reliable estimation of global potential. However, it is widely agreed that this potential could exceed 120 GW but due to geographical, technical and other barriers and constraints; till now only a small percentage of it has been harnessed.

UK is having the greatest tidal power capacity of more than 10 GW. The Pentland Firth is considered one of the world′s best site for tidal power as the tides here shifts from the Atlantic into the North Sea and also the water is forced through a long narrow channel. The Bay of Fundy in Canada is having the potential to generate 30 MW of power. China has abundant tidal power resource with an estimated potential of 3.5 GW. Argentina, North America, France, Russia and South Korea are other countries which have significant potential.

The current commercial installed capacity of tidal stream plant is of 4.3 MW with two largest plants namely Uldomok Tidal Power Station (South Korea) and MCT′s SeaGen (Strangford Lough, North Ireland). Further three commercial plants of total capacity 10.5 MW are under construction. The largest is of 6 MW MeyGen in Scotland. The second one is of 4 MW Cape Sharp Project (Bay of Fundy, Canada) and the third one are of 0.5 MW deployed by Sabella (Brittany, France). These have been shown in Fig. 10.

Development in India

The highest tidal currents in India have been found in the regions having large tidal range like Gulf of Khambat and Kutch and also in the Sunderbans areas. The various regions along the coastline have been categorized as given in Table 4:

The assessment of tidal stream potential in various regions is given in Table 5:

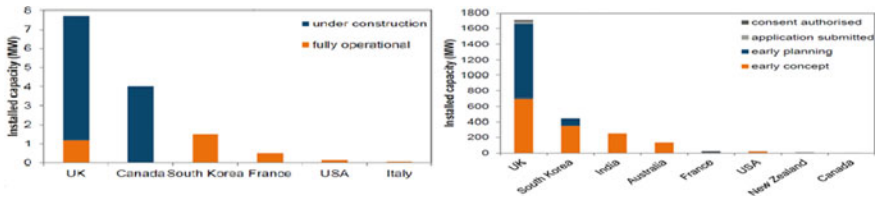

Fig. 10 Installed capacity of tidal stream in operation/under construction/conceptual/planning stage

Table 4 Categorization of coastal regions based on stream current (Afd 2014)

Coastal Regions	Tidal range (m)	Tidal stream current (m/s)	Classification
Gulf of Khambat	5–11	2.5	Class I Tidal Stream
Gulf of Kutch	4–9	3.0	Class I Tidal Stream
Sunderbans and Hoogly	4–7	2–3	Class I Tidal Stream
Maharashtra and South Gujarat Coast	2–4	1.5–2.5	Class II Tidal Stream
Orissa Coast	2–4	1.5	Class II Tidal Stream
Kerala and Karnataka Coast	1.0–1.5	1.0–1.5	Class III Tidal Stream
Andhra Coast	1–2	1.0	Class III Tidal Stream
Tamil Nadu Coast	1	0.8	Class IV Tidal Stream
Palk—Mannar Bay	1	0.6	Class IV Tidal Stream

Table 5 Tidal stream potential (Afd 2014)

Location	Site Conditions	Technology	Present Gross Assessment in MW
Gulf of Khambat	Depth—12.5 m Tidal Range—4 m Current—2.5 m/sec	Tidal stream turbine	950–1900
Gulf of Kutch	Depth—15 to 20 m Tidal Range—3.5 m Current—3.0 m/sec	Tidal stream turbine	2000

3 Barrier in the Development of Tidal Energy

There are four main barriers in the development of tidal energy:

- Technology Development
- Finance and Markets
- Environmental Issues
- Grid Issues.

The details have been discussed below:

3.1 Technology Development

For achieving global commercial success, two major bottlenecks—low turbine efficiencies and high equipment costs; need urgent and proper attention. At present, various technologies for harnessing already exist but great challenges arise due to lack of sufficient experience on materials to be used, its performance, placing the structures in a harsh and hostile sea environment, its life span, operation and maintenance of technologies and power plant. So, for the establishment and the growth of tidal market, it is absolutely necessary to develop a reliable technology as this issue also has impact on other barriers.

Hence in order to overcome this barrier; very effective, collaborative and focused efforts are required amongst the participating research Institutions, professional developers and concerned Governments agencies and policy makers. Further, more capital supports and incentives are to be provided for conducting research on new technologies, methodologies, materials to be used, model testing, functional prototype and pilot array development.

3.2 Finance and Markets

Globally, majority of the projects are funded by Government Agencies or by the professional technology developers themselves. At present; UK, South Korea, Ireland, France and Canada have well defined policies and framework to facilitate the research and for the technologies demonstration. Other potential countries have also started to frame active policy for harnessing marine energies. However, necessary financial framework conditions for sustaining on long term basis have not yet evolved. Hence, there is a need to develop new financial mechanism particularly for harnessing the tidal stream as full scale successful testing have already been done but for its commercial deployment, it requires a very serious market pull and support mechanisms. In this regard, some policy decisions are required to attract investors such as large capital grants, soft loans, project equity loans, tax exemption and other incentives and support mechanism to deploy it into pilot arrays which will provide a clear picture to market. Now with practical experience and performance data, industry will be able to understand the real situations and issues and will be in a position to reduce risk and cost. These measures will stimulate the confidence of investors. Up to 2010, globally small entrepreneurial companies had dominated the Tidal Energy Projects but during last four-five years, large engineering and turbine manufacturers companies have entered the market. Prominent amongst them are Alstom, Siemens, GE, Hyundai Heavy Industries, Voith Hydro, Kawasaki Heavy Industries and Andritz Hydro. Recently, for some of the prototypes; electrical power systems are supplied by GE. Further, some demonstration projects are also run by big companies such as Bord Gais Energy, GDF Suez and Iberdola.

3.3 Environmental Issues

The tidal power projects may also have some adverse effect on environment. It may impact the existing marine ecosystems and other economic activities particularly fishing in the coastal areas. The fixing of turbine in the ocean may impact the wave patterns and may also disturb the natural aquatic environment due to increased noise level during its installations, operation and maintenance.

Hence, it is necessary to monitor the power plant project right from the stages of installation of pilot projects, so that the impact on marine life including fish could be analyzed in a better way. Latest monitoring equipment such as video cameras, telemetry, drift nets and other measuring equipment should be incorporated in both pilot and commercial projects. It will help a lot in designing the mitigation measures. Currently, these data are mandatory requirements for allowing the installation of projects in ocean. So, large incentives and investments are required to develop and implement the new technology and infrastructures on commercial scale and to know in a scientific way the impacts of project on marine life and also on the activities along the coastline.

3.4 Grid Issues

One of the major concerns of the tidal energy projects is to have the grid availability near the proposed site. Often, the site of tidal energy resource lacks grid infrastructure and requires either development of new network lines or existing network up gradations, the cost of which falls on the developers. European countries such as Portugal, Spain, France and Netherland have advantageous position as it has high voltage transmission lines closer to shore. For these sites, grid may not be the critical issues but majority of the sea test sites have not yet developed the grid array and connections.

Further, another important aspect is the grid integration issue. Concerted R&D efforts should be done to provide the multi-purpose platform to integrate both tidal energy and offshore wind in order to reduce the Levelised Cost of Energy (LCOE) and give stimulation in both sectors.

4 Conclusions

During recent year, technology and other infrastructures development of tidal energy have made tremendous progress. Large numbers of companies are taking keen interest and deploying the pilot projects. Initially, its cost is very high but with the development and research, its cost will reduce significantly. Currently 521 MW of tidal range plant capacity already exists globally and 1.7 GW is under construction. There is a huge potential to harness the tidal current which as per widely accepted estimate could exceed 120 GW but due to geographical, technical and other barriers and constraints, till now only a small percentage of it has been harnessed. UK is having the greatest tidal power capacity of more than 10 GW. As India has 7500 km long coastline surrounded from three sides with estuaries and gulfs, Govt. of India has recognized its potential to harness both form of tidal energy. As per the current estimate of the Govt. of India, Ministry of New and Renewable Energy (MNRE), the tidal energy gross potential of India is of approximately 8000 MW, out which the Gulf of Khambat (Gujarat) alone has approximately 7000 MW potential. In spite of huge potentials, still the technological development is in the early stage and also its commercial deployment has not progressed as expected. These developments face four major bottlenecks—appropriate technology development, financial and market supports, environmental impacts and grid connection issues. In order to overcome these barrier; very effective, collaborative and focused efforts are required amongst the participating research Institutions, professional developers and concerned Governments agencies and policy makers.

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