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TIDAL ENERGY: A REVIEW

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ABSTRACT

The phenomenon of rise and fall in the ocean waters, called tides, is due to the attractive forces between the celestial bodies; Sun, Earth and the Moon. When the ocean water rises to a maximum extent, it is called spring tide and when they fall off to the lowest possible extent, it is called neap tide. With progress in technology, the usage of electric and electronic devices is exponentially increasing and there is a need to produce extra power other than the existing, in order to meet the future demands. Tidal energy can be considered as one of the best existing source of renewable energies. Unlike the wind, solar, thermal energy etc., tidal energy is something that has a long term perspective and it can be forecasted more accurately. Tidal energy is clean and not depleting. Because of these features it is unique and suitable to use it as a power generating source in the future. There are various types of tidal power plants across the world with varying tidal elevation. Also, the method of conversion of tidal energy into electrical energy is site specific. But generally, the method followed for extracting energy from tides is similar to the conventional hydroelectric power plants. In this paper, the tides at some locations across the world and along the Indian coast, tidal power plants across the world, resource allocation of tidal power plants, advantages and disadvantages of tidal power will be reviewed from the literature.

Keywords: *Tidal energy, tidal barrage, tidal stream, electrical energy.*

1. INTRODUCTION

There are numerous diverse forms of ocean energy that are being explored as potential sources for energy extraction. Some of them are ocean current energy, tidalenergy, wave energy, offshore wind energyand thermal energy (Nicholls and Turnock, 2008). Even though the tidal power is still an immature concept, it is definitely a major contributor for electricity generation from renewable sources in the near future(Shaikh and Shaikh, 2011).

The occurrence of tides was witnessed from Roman times and this energy was used on rivers such as the joint estuary of the Tigris, the Tibet River in Rome and Euphrates Rivers even much earlier (Charlier and Finkl, 2009). The flow of water in the form of tides, induced due to the relative positions of the planets Sun-Earth-Mooncan surely be considered as one of the reliable sources of energy if suitable systems are designed with an economic plan (Nicholls and Turnock, 2008). In the recent past, use of renewable energy resources for the extraction of energy has been the point of discussion (Cave and Evans, 1984; Bryden et al., 1995; Sodin, 2001).

Researchers working on renewable energy are mainly interested to extract the energy from tides because of its advantages over other forms of renewable energies as the forecasting of tides is easier and accurate from time and magnitude point of view, the density of sea water is much denser than wind, lack of extreme flow speeds and negligible asthetic damage. (Shaikh and Shaikh, 2011).

1.1 Tides

Tides are the periodic motion of the waters of the sea due to the inter-attractive forces between the celestial bodies. Tides are very long-period waves that move through the oceans in response to the forces exerted by the moon and sun. Tide and current are not the same. Tide is the vertical rise and fall of the water and tidal current is the horizontal flow. In simple words, the tide rises and falls, the tidal current floods and ebbs. The principal of tidal forces are generated by the Moon and Sun. The Moon is the main tide-generating body. Due to its greater distance, the Sun's effect is only 46 per cent of the Moon's.

1.2 Energy from the tides

There are three types of tides: diurnal, semidiurnal and mixed. (Hagerman G., Polagye B, 2006).Tidal Energy is one of the new and evolving technologies, which is commercially not viable and still in Research & Development (R&D) stage. Tidal energy is inexhaustible and can be considered as a renewable energy source (Shaikh and Shaikh, 2011). Itis an advantage because it is less vulnerable to climate change; while the other sources are all vulnerable to the random changes in climate(Nicholls and Turnock, 2008). The review given by the Energy Technology Support Unit (ETSU) on the Tidal Stream Energy was the initial attempt to estimate the energy from tidal stream resources in the UK (ETSU, 1993). The points marked by the ESTU were later studied and modified in 2001 in a document submitted to the UK Department of Trade and Industry (DTI) by Binnie, Black and Veatch.
Most of the existing technology used for tidal energy conversionis from the wind power industry (Bahaj et al., 2007; Batten et al, 2007; Fraenkel, 2002). Researchers have predctited that UK has is capable to produce over 20% of its electrical needs from its tidal resources (Callaghan, 2006). It is also a fact that the studies carried out so far in predcting the energy that can be extracted from tides, has only focused on the past and present availability of the energy. But it is also important to consider and address the effects of exploiting the renewable energy sources for energy extraction. There has to be an understanding among the developers as to when and where to stop the energy extraction so that there is minimum or no disturbance caused to the regular natural phenomenon.

1.3 Tidal energy in India

The tides that are generated along some parts of the Indian coastline have the potential to extract energy from the turbines. The tidal elevation in India is as high as 8.5 m at Bhavnagar, Gujaratand as low as 0.5 m at the Southern part of India. Survey of India predicts tide levels at somelocations along the Indian coastline and Tide Tables are published for every year (Sanil Kumar V. et al, 2006).
As per the studies carried out by Central Water and Power Commission (CWPC) in 1975, the Gulf of Kutch and Gulf of khambhatin Gujarat and Sunderbans area in West Bengal are the only suitable sites in India for the production of Tidal Energy. In 1980s, Central Electricity Authority (CEA) took up a study for the assessment of tidal energy potential in India. CEA listed few places of Potential Tidal Energy extraction in India shown in Table 1.

No tidal power generation plant has been installed in India due to its high cost of generation of electricity and lack of techno-economic viability. However, there are proposals for setting up of tidal power stations at Gujarat.

Table 1. Tidal Energy Potential in India

Region	State	Tidal potential (MW)
Gulf of Khambhat	Gujarat	7000
Gulf of Kutch	Gujarat	1200
Gangatic Delta, Sunderbans	West Bengal	100

1.3.1 Demonstration Project at Sunderbans

A report was submitted by West Bengal Renewable Energy Development Agency (WBREDA) in 2001 for setting up a 3.65 megawatt capacity tidal power station at Durgaduani Creek in Sundarbans Island of West Bengal. These details were submitted to the Ministryon June 2006. Also, WBREDA entered into a MoU with the National Hydroelectric Power Corporation Limited (NHPC), Faridabad for updating of the Project Report and its execution. The updated Report prepared by NHPC was received by the Ministry in November, 2007. The NHPC Limited was given responsibility to complete the project. However, the project has been discontinued due to very high tender cost.

1.3.2 Tidal Power Projects in Gulf of Kutch, Gujarat

A committee was established under the Central Electricity Authority (CEA) on the 900MW Kutch Tidal Power Project for estimating the cost of the project. The project was not found to be commercially viable due to high capital cost as well as high cost of generation of electricity.

In January 2011, Gujarat signed a MoUwith Gujarat Power Corporation Ltd. (GPCL) for establishing a 250 MW tidal power project at Mandavi district in Gulf of Kutch. GPCL has initially started a 50MW tidal power project in Kutch. GPCL has made a request for grant for the tidal power plant to Ministry of New and Renewable Energy (MNRE).

The experience gained in the above project will decide the future course of action for the advancement of tidal energy in India.

1.4 Tidal energy around the world

The necessity to reduce CO_2 emissions and gradual increase in cost of fossil fuel has resulted in a significantly increased use of tidal energy (Nicholls and Turnock, 2008). Today, tidal energy around the world is increasingly being considered as a potential source of renewable energy (Bryden and Scott, 2007). Extreme tides are found in many locations across the globe. Some of them are: the Pentland Firth, Scotland; the Severn estuary; the Aleutians; the fjords of Norway; the Philippines; the Straits of Messina, Italy; the Bosporus, Turkey; the English Channel; Indonesia, and the straits of Alaska and British Columbia.

The first major hydroelectric plant was put to operation in 1967 that used the energy of the tides to generate electricity. It producedabout 540,000 kW of electricity (Charlier and Finkl, 2009). Studies have shown that the European territorial waters have 106 locations for extracting tidal energy that would provide electricity of 48 TW per year. It is estimated around 50,000 MW of installed capacity being achievable along the coasts of British Columbia alone. There are greater predictions of extracting energy of about 90,000 MW off the North West coast of Russia and about 20,000 MW at the inlet or Mezen river and White Sea. There are also estimations along the West coast of India having potential to generate 8,000MW.

Table 2 gives the highest available tidal levels in some of the regions that have the potential to establish tidal power stations. Tidal power plants have already been set up at some of these places and some are still in the planning phase.The main characteristics of four large-scale tidal power plants that were constructed after World War II and currently exist are given in Table 3.

Table 2. Highest tides of the global ocean (Gorlov A. M., 2001)

Site	Country	Tidal elevation (m)
Bay of Fundy	Canada	16.2
Severn Estuary	England	14.5
Port of Ganville	France	14.7
La Rance	France	13.5
Puerto Rio Gallegos	Argentina	13.3
Bay of Mezen (White Sea)	Russia	10
Penzhinskaya Guba (Sea of Okhotsk)	Russia	13.4

Table 3. Existing large tidal power plants (Gorlov A. M., 2001)

Site	Country	Bay area (km^2)	Avg. tide (m)	Installed Power (MW)
La Rance	France	22	8.55	240
Kislaya Guba	Russia	1.1	2.3	0.4
Annapolis	Canada	15	6.4	18
Jiangxia	China	1.4	5.08	3.9

2. METHODS OF TIDAL ENERGY EXTRACTION

Different methods have been suggested by authors for the extraction of tidal energy. However the basic principle behind the methods remains same. However, there are two primary methods to extract energy from the tides.

a. Estuaries into which large amounts of ocean water flows in due to high tidal range, are captured behind barrages and the turbines are rotated by utilizing the potential energy of the stored water.
b. The kinetic energy of moving water can be used to extract energy similar to the principle of extraction of wind energy.

Both methods that are mentioned above have been suggested and followed and each has its own advantages and disadvantages (Bryden and Melville, 2004). It may also be possible to employ pumping strategies for barrages to obtain better efficiency and to match electricity demand better (MacKay, 2007).

The devices that are used in the energy generation vary in size, shape and specifications. ISSC (2006) has classified the devices into three types:

a. Tidal barrages that store tidal flow and generate power through discharge.
b. Tidal fences which block a passage and extract energy in either or both directions of tidal flow.
c. Tidal current devices which are fixed or moored within a tidal stream.

2.1 Tidal barrage

Tidal barriage is a structure generally built across the mouth of the estuary through which the water flows in and out of the basin. The tidal barriage has sluice gates that allows the flow of water in and out of the basin. The water flows into the bay during high tide and the water is retained by closing the sluice gates at the beginning of low tide. The barrage gates are controlled by knowing the tidal range of the location and operating it at right times of the tidal cycle. There are turbines located at the sluice gates which produce electricity when the gates are opened during the low tide. Using this principle, authors have mentioned different ways of extraction of energy like ebb generation, flood generation, ebb and flood generation, pumping, two basin schemes etc. Figure 1 shows the Plan view of a hypothetical tidal barrage. Even though the barrage method has high theoretical efficiency, only one large scale tidal barriage has been constructed at La Rance, France (Blunden and Bahaj, 2006).

The advantage of using barrage to method to generate electricity in comparision with fossil fuels is that it reduces the greenhouse effects, to provide a better environment. La Rance tidal power plant, France is an example for barrage method.On the top of the barrage there is a four-lane highway that cuts 35 km of distance between the towns of Saint Malo and Dinard representing.

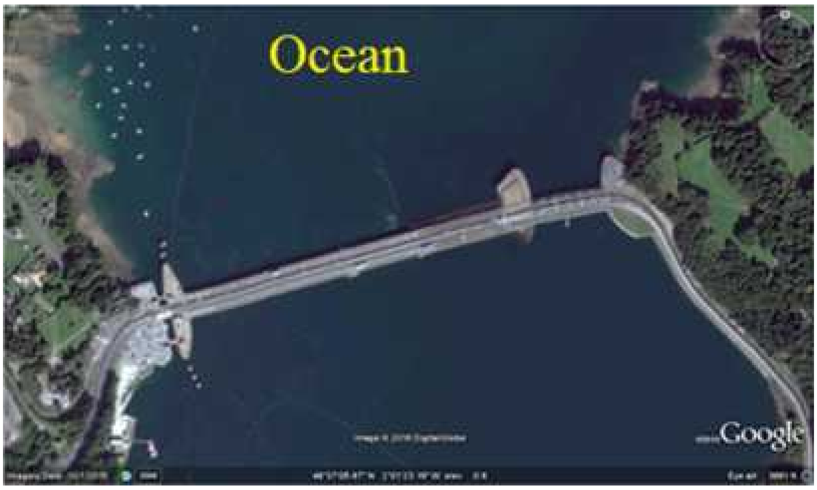


Figure 1. Top view of La Rance tidal power plant barrage (750m in length)

2.2 Tidal stream energy

In the early 1990s, tidal power was mainly focused on harnessing the tidal flow and generating the energy by means of potential storage rather than through tidal stream. Tidal stream technologies have made massive progress towards commercialisation in the last decade. Extensive research is being carried out in UK waters related to tidal stream energy. UK has a target at achieve 20% of its electricity requirement through ocean resources by 2020. About 40 energy converting machines are being developed and prorotypes are being tested in the labs and in waters of UK (Irena, 2014). Since the tidal stream energy is still a emerging technology, it has no standardizations, but variety of devices are being developed to make use of the water flow to extract electricity. However, the efficiency of each of the devices has to be flawlessly examined by extensive testing to choose the appropriate device for a particular location.

2.3 Calculation of tidal energy

The total tidal energy is the energy due to the tidal stream (kinetic energy) and the energy due to release of the stored water in the basin (potential energy). It is also a fact that the increase in tidal variation or the tidal stream energy results in increase of energy extraction to a large extent (Shaikh and Shaikh, 2011).

2.3.1 Kinetic energy

The kinetic energy of the stream flow flowing across the cross section with a velocity is given by (Bryden et al., 2004).

$$P = \frac{1}{2}\rho \qquad V^3 \tag{1}$$

$\rho$is the density of sea water (kg/m^3)
C_p is the power coefficient
A is the area of cross section of the channel (m^2)
V is current velocity (m/s)

The power output or the efficiency of the turbine "ξ" depends on the design of the turbine. The power output for a turbine from these kinetic systems can be obtained by the following equation (Shaikh and Shaikh, 2011).

$$P = \frac{\xi \quad V^3}{2} \qquad (2)$$

$\xi$is turbine efficiency
P is power generated (in watts)
ρisdensity of the water (seawater is 1025 kg/m³)
A is sweep area of the turbine (in m²)
V is velocity of the flow

2.3.2 Potential energy

The potential energy is mainly dependent on the tidal prism of the basin. Potential energy obtained due to the stored water can be calculated as (Gorlov, 2001; Shaikh and Shaikh, 2011).

$$E = \frac{1}{2}A \quad gh^2 \qquad (3)$$

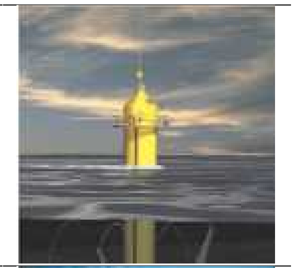
h is the vertical tidal range,
A is the horizontal area of the barrage basin,
$\rho$is the density of water = 1025 kg per cubic meter (seawater varies between 1021 and 1030 kg/m^3)
g is the acceleration due to the Earth's gravity = 9.81 m/s^2

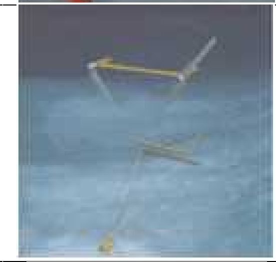
From equation 3, it can be seen that the potential energy varies with square of tidal range. So, a barriage should be placed in such a location where it is possible to achieve maximum storage head.Black and Veatch (2003) suggest that the ideal water depths to achieve the best possible power output at few potential sites around the UK range between 25 and 40 m and the recommend diameter of the rotor to range between 10 m and 20 m. (Frost et. al, 2015). The inlets that are between islands having large basin area are considered to have a greater amplification effect because of the reduction in the throat area and the water depth relative to the surroundings, producing a venturi effect. This accelerates the water as it is forced through a channel with a smaller cross-sectional area (Bryden I G and Melville G T, 2004).

2.4 Tidal energy devices

There are wide range of tidal energy devices used for energy extraction based on site conditions. The details of some of them is given in Table 4.

Table 4. Tidal energy extraction devices

Turbine	Power Output	Description	Image
Seagen, Marine Current Turbines Ltd. UK	1 MW	Twin two bladed rotor, sheath mounted, horizontal axis tidal turbine	
The Blue Concept,Hammerfest Strom, Norway	1 MW	Three bladed pile mounted horizontal axis tidal turbine	

THG, Tidal Hydraulic Generator	3 MW	Array of four bladed horizontal axis turbines attached to a gravity mounted frame	
TidEL SMD Hydrovision, UK	1 MW	Twin two bladed tethered rotor, able to yaw into the current	
Stingray, Engineering Business Ltd., UK	500 kW	Oscillating Hydroplane	
Blue energy, Blue energy Inc., Canada	500 kW	Four bladed, moored, surface piercing, vertical axis turbine	

3. RECOMMENDED SITES FOR INSTALLATION OF TIDAL POWER PLANTS

Some preliminary standards are given by Couch and Bryden to identify sites that are suitable for the development of a tidal energy extraction. The most important variables generally considered are:
1. The local water depth: Existing device technology concepts are generally limited to operational water depths of 25–45 metres.
2. The location of the nearest exploitable grid connection: For an immature industry, the economics of tidal energy extraction require easy access to a nearby grid connection with spare capacity; otherwise the capital cost cannot be viably recouped across the life of the project.
3. An energetic and persistent resource: Large mean spring and neap tide velocities are highly desirable. Some sites have the added advantage of minimizing the low velocity periods of the tidal cycle as the local dynamics ensure that the tidal flow reverses through the slack period at an accelerated rate. The sites that the developers are interested to extract energy tend to have peak spring tidal velocities of 3+ m/s.

If these three primary criteria are met, a site is considered to have solid potential for future development. The majority of coastal locations can be rejected out of hand by consideration of just these three variables (Couch and Bryden, 2006).

The English Channel, theArctic Ocean, The Gulf of Mexico, The Amazon, The Straits of Magellan and Taiwan are some of the possible locations for locationg tidal devices. Table 6 shows some potential sites for tidal power installations.There are estimates that the energy that can be globally extracted is around 1800 TWh/year (Nicholls and Turnock, 2008). But, it has to be taken care that the effect on environment, economic and social constraints have to ve addressed (Sun X et al., 2008). It is suggested that 10% of the extraction of energy can be considered as guideline for harnessing renewable energy resources (Bryden I.G. et al., 2004). The estimated construction costs for existing and proposed tidal barrages are given in Table 5.

Table 5. Estimated construction costs for existing and proposed tidal barrages

Barrage	Country	Capacity (MW)	Power Generation (GWh)	Construction costs (Million USD)	Construction costs per kW (USD/kW)
		Operating			
La Rance	France	240	540	817	340
Sihwa Lake	Korea	254	552	298	117
		Proposed/planned			
Gulf of Kutch	India	50	100	162	324
Wyre barrage	UK	61.4	131	328	534
Garorim Bay	Korea	520	950	800	154
Mersey barrage	UK	700	1340	5741	820
Incheon	Korea	1320	2410	3772	286
Dalupiri Blue	Philippines	2200	4000	3034	138
Severn barrage	UK	8640	15600	36085	418
Penzhina Bay	Russia	87000	200000	328066	377

Note: Cost equivalent for 2012
Based on Wyre Energy Ltd., 2013.

Table 6. Some potential sites for tidal power installations (Gorlov A. M., 2001)

Site	Country	Bay area (Km^2)	Avg. Tide	Potential Power (MW)
Passamaquoddy	USA	300	5.5	400
Cook Inlet	USA	3100	4.35	Up to 18000
Mezen	Russia	2640	5.66	15000
Tugur	Russia	1080	5.38	6790
Severn	UK	490	8.3	6000
Mersey	UK	60	8.4	700
San Jose	Argentina	780	6.0	7000
Carolim Bay	Korea	90	4.7	480
Secure	Australia	130	8.4	570
Walcott	Australia	260	8.4	1750

Technology and economics, however, dictate that only those areas where currents can exceed 2m/s might be suitable for exploitation (Bryden I G and Melville G T, 2004).

4. ADVANTAGES AND DISADVANTAGES OF TIDAL POWER

Advantages:

- Tidal power is a renewable and sustainable energy resource.It reduces dependence upon fossil fuels.
- It produces no liquid or solid pollution.It has little visual impact.
- Tidal power exists on a worldwide scale from deep ocean waters.
- Tidally driven coastal currents provide an energy density four times greater than air, which means that a 15m diameter turbine will generate as much energy generated by a 60mdiameter windmill.
- Tidal currents are both predictable and reliable, a feature which gives them an advantage over both wind and solar systems. Power outputs can be accurately calculated far in advance, allowing for easy integration with existing electricity grids.

Disadvantages:

- High cost of construction, installation and generation.
- Barrages can disrupt natural migratory routes for marine animals and normal boating pathways.
- Turbines can kill up to 15% of fish in area, although technology has advanced, the turbines have to move slow enough not to kill many.
- Flooding and ecological changes.
- Research is still in initial stages.

5. CONCLUSIONS

- The tidal energy industry has to develop a new generation of efficient, low cost and environmentally friendly apparatus for power extraction from free or ultra-low head water flow.
- The negative environmental impacts of tidal barrages are probably much smaller than those of other sources of electricity, but are not well understood at this time. It is important to consider the influence of energy extraction while estimating the available energy from a potential tidal energy site.
- The future costs of other sources of electricity, and concern over their environmental impacts, will ultimately determine whether humankind extensively harnesses the gravitational power of the moon.
- As yet the majority of this tidal energy resource is under-utilised; however, if effectively captured using suitably engineered systems, it could be capable of making a major contribution to our future energy needs.

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