ANALELE UNIVERSITĂȚII
“EFTIMIE MURGU” REȘIȚA
ANUL XXII, NR. 2, 2015, ISSN 1453 - 7397

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Identification of the Opportunities for Future Development of Tidal Energy

An overview of status of development of tidal energy is given in this article. To reduce the dependance on fossil fuel and imported energy resources, the need for ocean energy is a global demand in developing countries. The ability to directly extract from the world’s oceans may be in the form of mechanical energy from waves, tides, or currents, or in the form of thermal energy from the sun’s heat. This paper identifies the opportunities for future development of tidal energy.

Keywords*: Tidal energy; Tidal barrage*; *Tidal turbine*; *Power.*

1. Introduction

Energy is an important entity for the economic development of any country. On the other hand, fossil fuels meeting a great portion of the energy demand are very scarce and their availability is decreasing year by year. Nowadays, power generation from renewable energy has become increasingly important because it confers better energy security and smaller environmental impact with respect to conventional energy sources. These energies are named as follows: solar, wind, geothermal, biomass, hydroenergy, and ocean energy (e.g. ocean thermal, tidal, wave, and ocean currents). As one class of renewable energy, although ocean energy currently shares a very small proportion in energy system, it has greater potential for development. The success of ocean energy power generation depends a lot on the economics because the payback period must be reasonably short. The challenges of each technology type (e.g. material corrosion, marine biofouling of turbine blades, problems associated with hydrodynamic and structural design and construction system and methodology for power plant installation) for harnessing ORE have been discussed in detail by Mueller and Wallace [1]. The designer must consider these challenges to reduce costs and the financial risk. Ocean energy can be categorised as tidal barrage, tidal current energy, wave energy, ocean thermal energy conversion (OTEC) power, and salinity gradient power [2], as illustrated in Figure 1.

In this paper, tidal energy driven by the gravitational pull of the moon has been investigated as substantial energy resources in the ocean.

2. Tidal Energy

2.1 Tidal barrage

Tidal energy is the potential energy of water caused by flood and ebb tide. Its principle of operation is similar to hydroelectric generation. Barrage-based systems designed to convert the potential energy stored behind the barrage into electricity. According to Figure 2, sea water is allowed to flow through the barrage via turbines, which can provide power during either the ebb tide or flood tide or during both tides. The energy of tidal is approximately proportional to the square of the tidal range and area of the water trapped in the barrage. Tidal Barrages have been used commercially in France since 1966, in Canada since 1984, and in Korea since 2011.Tidal barrages can reach up to 80% energy conversion efficiency [3]. In Table 1 some of the main tidal power generation systems that have been built and their principal characteristics are listed. The Shihwa Lake tidal barrage in South Korea is the world's largest barrage with a capacity of 254 MW [4]. La Rance is the oldest and the second largest tidal barrage with a capacity of 240 MW, operating with 24 reversible turbines and a hydrostatic head of 5 m. [4]. The Annapolis Royal power station with a capacity of 20 MW is established on the Bay of Fundy coastline of Nova Scotia, the first tidal power plant in North America [4]. The Bay of Fundy is known for the largest tidal changes in the world (a difference between high and low tides of as much as 50 feet).

Tidal energy barrages have a number of environmental impacts that vary in scale depending on the type of barrage. The largest disadvantage of tidal power is the effect a tidal station on the plants and animals which live within the estuary. Fish and marine mammals may suffer damage by collision with the barrage and turbines.

The average tidal energy potential can be estimated as follows[5]:

$$P = AR^2 g / 2T(\text{Watts}) \tag{1}$$

Where: P is the average tidal potential energy extractable, ρ=Density of water, A= Barrage surface area (m^2), R= Tidal range(m), g= Acceleration due to gravity(m/s^2) and T=Tidal period (s).

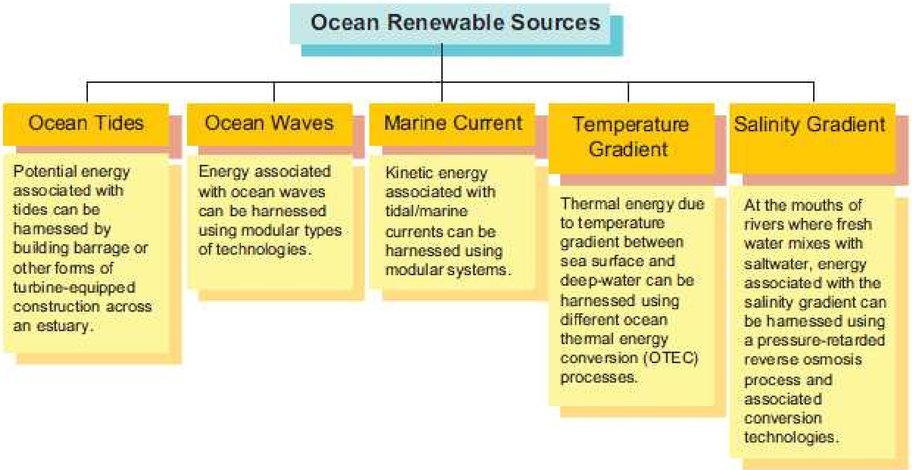

Figure 1. Ocean renewable sources [2]

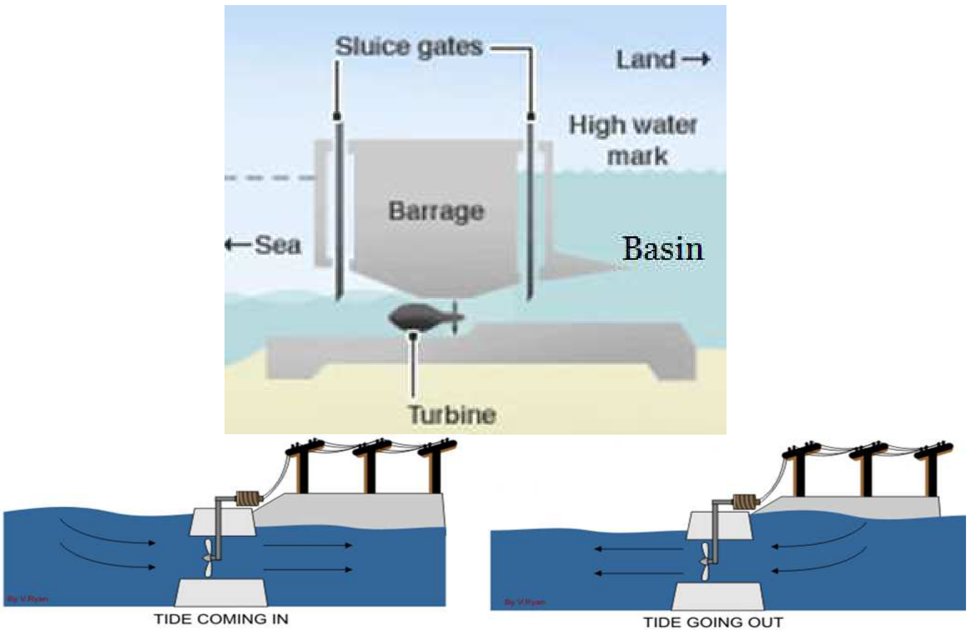

Figure 2. Schematic design of a Tidal Barrage

Table 1. Some of the major tidal impoundment sites.

Location	Head, m	Mean Power, MW	Production, GWh/year
Minas-Cobequid, North America	10.7	19,900	175,000
White Sea, Russia	5.65	14,400	126,000
Mont Saint-Michel, France	8.4	9700	85,100
San Jose, Argentina	5.9	5970	51,500
Shepody, North America	9.8	520	22,100
Severn, UK	9.8	1680	15,000

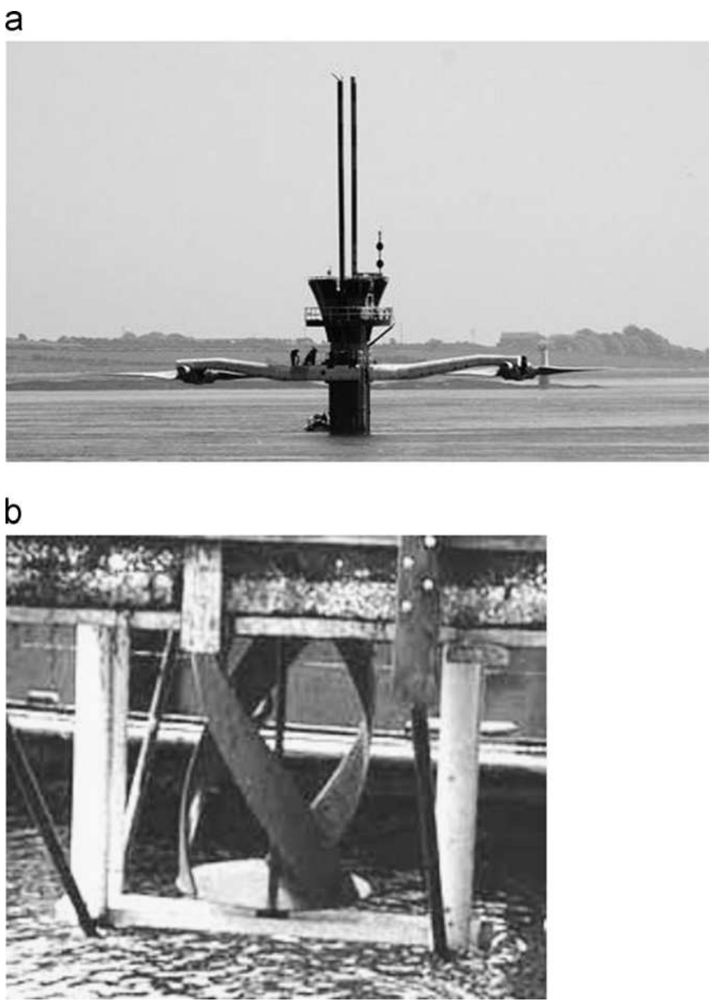

Figure 3. Tidal turbine:(a) horizontal-axistidalturbine, (b) vertical-axistidal turbine [2].

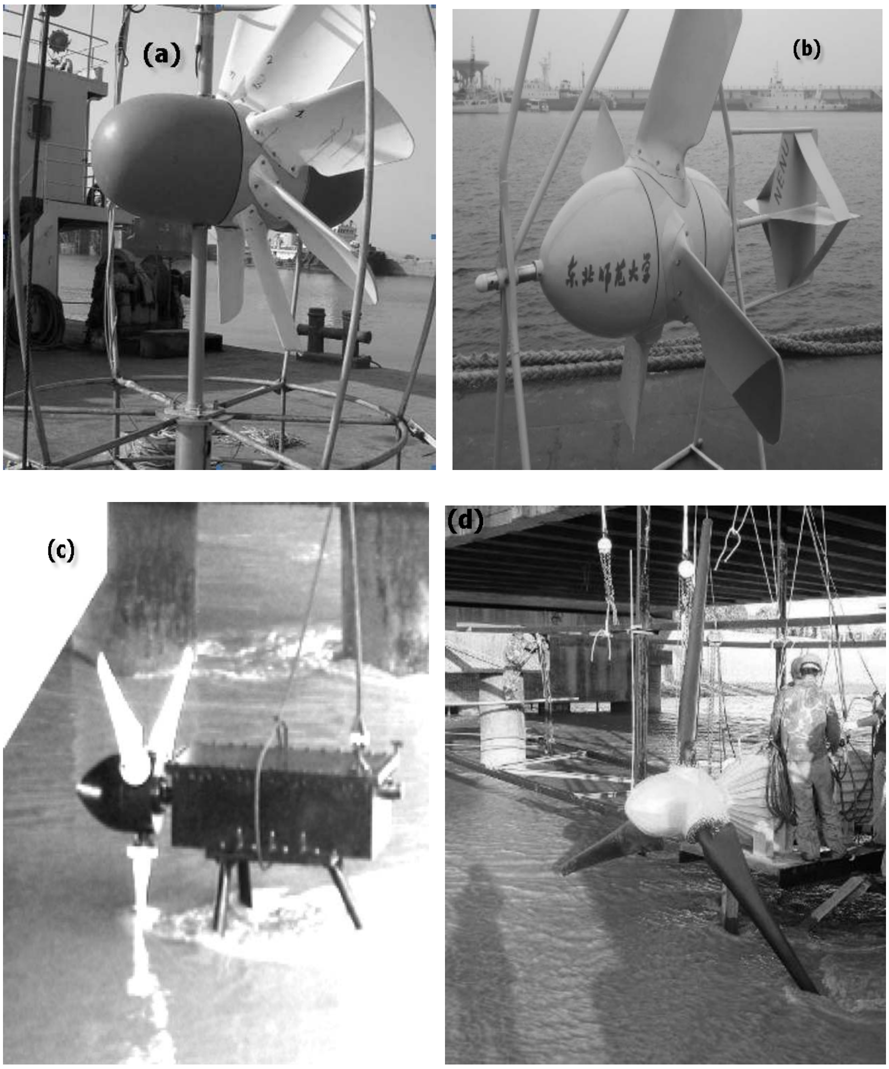

Figure 4. Horizontal axis tidal current turbine for (a)1 kW, (b) 2 kW, (c) 5 kW, (d) 25 kW [6].

2.2. Tidal current turbines

Tidal current power is currently more frequently mentioned than tidal barrages. Tidal barrages have high capital costs and significantly alter coastal and estuarine ecology. Tidal turbine is widely accepted as a cost effective method to harness ocean energy compared with wave energy, OTEC power, and salinity gradient power [6]. These devices function without use of impoundments or barrages, similar to how a wind turbine draws. Tidal turbines can be categorised as either vertical-axis, or horizontal-axis turbines [2] (see Figure 3). The vertical-axis turbine is able to capture the energy from various directions without adjusting the position of turbine, whereas the horizontal-axis turbine may be able to capture more tidal energy. Figure 4 shows the horizontal axis tidal current turbine with capacity of 1, 2, 5 and 25 kW. The intensity of water level height ranges or tidal current velocities will yield higher electricity generation. For example, 1 kW of power can be extracted in a current of 0.6 m/s or a maximum power of 29.08 kW can be produced in a current of 2.4 m/s [6].

Figure 5 Flexible vane turbine [6].

Figure 6. 5 kW tidal current conversion device with flexible vane turbine [6].

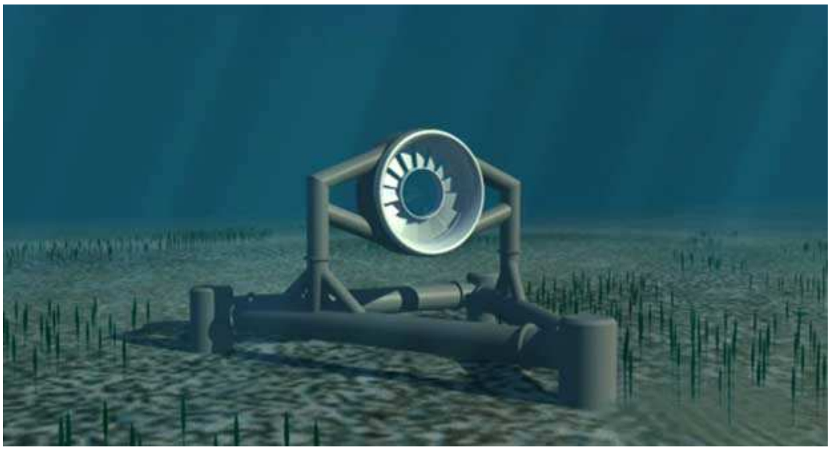

Figure 7. Tidal Turbine by OpenHydro [8].

Hydrokinetic tidal power is derived from the conversion of the kinetic power in moving water to electricity and depends on the area of water intercepted by the device (a circular area for a horizontal axis rotor, rectangular area for a vertical axis rotor), the cube of the water velocity, and the efficiency at which the device extracts the power in the water and converts it to electricity [7]. Mathematically this is described as:

$$P = \frac{1}{2}\rho U^3 A \eta \quad (2)$$

where P is the power generated by the turbine, ρ is the density of seawater (nominally 1,024 kg/m3), U is the current velocity, A is the area of water intercepted by the device, and η is the water-to-wire efficiency of the device.

Figure 5 shows a Flexible vane turbine that the rotation direction of the turbine's rotor had nothing to do with the flow direction and the turbine had relatively high efficiency, which made it quite fit for being used in tidal currents [6]. All hydrokinetic turbines include a set of common components: rotors, power train, mooring, and foundation. Additionally, all devices or arrays require electrical transmission to shore and protection against biological fouling. Figure 6 shows a 5 kW tidal current conversion device with flexible vane turbine in Zhaitang Island Channel.

The OpenHydro turbine (Figure 7) is a high-solidity horizontal axis rotor with symmetric, fixed-pitch blades that designed to be deployed directly on the seabed by a tripod gravity base [8]. OpenHydro is an Irish energy technology company whose business is the design and manufacture of marine turbines for generating renewable energy from tidal streams. OpenHydro also operates a grid-connected test facility at the European Marine Energy Centre (EMEC) in Orkney, Scotland, where it tests its turbine technology at 6 m (250 kW) scale for performance and environmental effects. Unfortunately, the environmental impact of tidal current turbines is not well known yet [9, 10].

Table 2 shows a summary of the capital cost breakdown for a 'typical' first generation tidal energy device. Table 3 shows the development costs of offshore wind. A successful tidal generation industry needs to provide the ability for tidal power to produce electricity at a cost comparable to offshore wind.

Table 2. Typical tidal device costs breakdown (Carbon Trust, UK) [11]

Component/system	Cost k€/MW	Share (%)
Turbine ex works incl. transport	815	49
Transformer and main cable	270	16
Inter-turbine cabling	85	5
Foundations	350	21
Eng. design and proj. management	100	6
Environmental assessment	50	3
Miscellaneous	10	<1
Total	1680	~100

Table 3. Analysis of offshore wind developments [11]

Project	Commissioned	No. of turbines	Turbine size (MW)	Array capacity (MW)	Unit cost (M€/MW)
Middelgrunden (DK)	2001	20	2	40	1.2
Homs Rev I (DK)	2002	80	2	160	1.7
Samso (DK)	2003	10	2.3	23	1.3
North Hoyle (UK)	2003	30	2	60	2
Nysted (DK)	2004	72	2.3	165	1.5
Scroby Sands (UK)	2004	30	2	60	2
Kentish Flats (UK)	2005	30	3	90	1.8
Barrows (UK)	2006	30	3	90	–
Burbo Bank (UK)	2007	24	3.6	90	2
Lillgrunden (S)	2007	48	2.3	110	1.8
Robin Rigg (UK)	2008	60	3	180	2.7

3. Conclusions

Tidal energy is a kind of new energy which is both renewable and pollution-free so that the tidal power generation is increasingly popular in the world. Barrages can be built across the mouths of natural tidal basins with sluice gates. Water can be allowed to rise on one side of the sluice until enough of a hydraulic head is built up to power a turbine. Tidal current power has many advantages over its other tidal energy rivals. The turbines are submerged in the water and are therefore out of sight. They don't pose a problem for navigation and shipping and require the use of much less material in construction. Tidal generation is an immature technology and making significant reductions to both capital and operating costs is very vital to produce electricity at a cost comparable to offshore wind.

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