Tidal Power: An Effective Method of Generating Power

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Abstract—This article is about tidal power. It describes tidal power and the various methods of utilizing tidal power to generate electricity. It briefly discusses each method and provides details of calculating tidal power generation and energy most effectively. The paper also focuses on the potential this method of generating electricity has and why this could be a common way of producing electricity in the near future.

Index Terms — dynamic tidal power, tidal power, tidal barrage, tidal steam generator.

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1 INTRODUCTION

TIDAL power, also called tidal energy, is a form of hydropower that converts the energy of tides into electricity or other useful forms of power. The first large-scale tidal power plant (the Rance Tidal Power Station) started operation in 1966.

Although not yet widely used, tidal power has potential for future electricity generation. Tides are more predictable than wind energy and solar power. Among sources of renewable energy, tidal power has traditionally suffered from relatively high cost and limited availability of sites with sufficiently high tidal ranges or flow velocities, thus constricting its total availability. However, many recent technological developments and improvements, both in design (e.g. dynamic tidal power, tidal lagoons) and turbine technology (e.g. new axial turbines, cross flow turbines), indicate that the total availability of tidal power may be much higher than previously assumed, and that economic and environmental costs may be brought down to competitive levels.

Tidal power traditionally involves erecting a dam across the opening to a tidal basin. The dam includes a sluice that is opened to allow the tide to flow into the basin; the sluice is then closed, and as the sea level drops, traditional hydropower technologies can be used to generate electricity from the elevated water in the basin.

2 GENERATION OF TIDAL ENERGY

Tidal power is the only form of energy which derives directly from the relative motions of the Earth–Moon system, and to a lesser extent from the Earth–Sun system. Tidal forces produced by the Moon and Sun, in combination with Earth's rotation, are responsible for the generation of the tides. Other sources of energy originate directly or indirectly from the Sun, including fossil fuels, conventional hydroelectric, wind, biofuels, wave power and solar. Nuclear energy makes use of Earth's mineral deposits of fissile elements, while geothermal power uses the Earth's internal heat which comes from a combination of residual heat from planetary accretion (about 20%) and heat produced through radioactive decay (80%).

Tidal energy is extracted from the relative motion of large bodies of water. Periodic changes of water levels, and associated tidal currents, are due to the gravitational attraction of the Sun and Moon. Magnitude of the tide at a location is the result of the changing positions of the Moon and Sun relative to the Earth, the effects of Earth rotation, and the local geography of the sea floor and coastlines.

Because the Earth's tides are ultimately due to gravitational interaction with the Moon and Sun and the Earth's rotation, tidal power is practically inexhaustible and classified as a renewable energy resource.

A tidal generator uses this phenomenon to generate electricity. Greater tidal variation or tidal current velocities can dramatically increase the potential for tidal electricity generation.

The movement of the tides causes a continual loss of mechanical energy in the Earth–Moon system due to pumping of water through the natural restrictions around coastlines, and consequent viscous dissipation at the seabed and in turbulence. This loss of energy has caused the rotation of the Earth to slow in the 4.5 billion years since formation. During the last 620 million years the period of rotation has increased from 21.9 hours to the 24 hours we see now; in this period the Earth has lost 17% of its rotational energy. While tidal power may take additional energy from the system, increasing the rate of slowdown, the effect would be noticeable over millions of years only, thus being negligible.

2.1 Generating methods

Tidal power can be classified into three generating methods: Tidal stream generator, Tidal barrage, Dynamic

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tidal power.

3 TIDAL STREAMGENERATOR

A tidal stream generator is a machine that extracts energy from moving masses of water, or tides. These machines function very much like underwater wind turbines, and are sometimes referred to as tidal turbines.

Tidal stream generators are the cheapest and the least ecologically damaging among the three main forms of tidal power generation.

Fig. 1. The world's first commercial-scale and grid-connected tidal stream generator.

3.1 Types of tidal stream generators

Since tidal stream generators are an immature technology, no standard technology has yet emerged as the clear winner, but large varieties of designs are being experimented with, some very close to large scale deployment. Several prototypes have shown promise with many companies making bold claims, some of which are yet to be independently verified, but they have not operated commercially for extended periods to establish performances and rates of return on investments.

3.2 Energy calculations

Various turbine designs have varying efficiencies and therefore varying power output. If the efficiency of the turbine "ξ" is known the equation below can be used to determine the power output of a turbine.

The energy available from these kinetic systems can be expressed as:

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

Where:
ξ = the turbine efficiency
P = the power generated (in watts)
ρ = the density of the water (seawater is 1025 kg / m³)
A = the sweep area of the turbine (in m²)
V = the velocity of the flow

Relative to an open turbine in free stream, depending on the geometry of the shroud shrouded turbines are capable of as much as 3 to 4 times the power of the same turbine rotor in open flow.

3.3 Resource assessment

While initial assessments of the available energy in a channel have focus on calculations using the kinetic energy flux model, the limitations of tidal power generation are significantly more complicated. For example, the maximum physical possible energy extraction from a strait connecting two large basins is given to within 10% by:

$$P = 0.22\, \rho\, g\, \Delta H_{max}\, Q_{max}$$

Where
ρ = the density of the water (seawater is 1025 kg / m³), g = gravitational acceleration (9.81 m / s2), ΔH_{max} = maximum differential water surface elevation across the channel, Q_{max}= maximum volumetric flow rate though the channel.

4 TIDAL BARRAGE

A Tidal barrage is a dam-like structure used to capture the energy from masses of water moving in and out of a bay or river due to tidal forces.

Instead of damming water on one side like a conventional dam, a tidal barrage first allows water to flow into the bay or river during high tide, and releasing the water back during low tide. This is done by measuring the tidal flow and controlling the sluice gates at key times of the tidal cycle. Turbines are then placed at these sluices to capture the energy as the water flows in and out.

4.1 Generating methods

The barrage method of extracting tidal energy involves building a barrage across a bay or river that is subject to tidal flow. Turbines installed in the barrage wall generate power as water flows in and out of the estuary basin, bay, or river. These systems are similar to a hydro dam that produces Static Head or pressure head (a height of water pressure). When the water level outside of the basin or lagoon changes relative to the water level inside, the turbines are able to produce power.

The basic elements of a barrage are caissons, embankments, sluices, turbines, and ship locks.

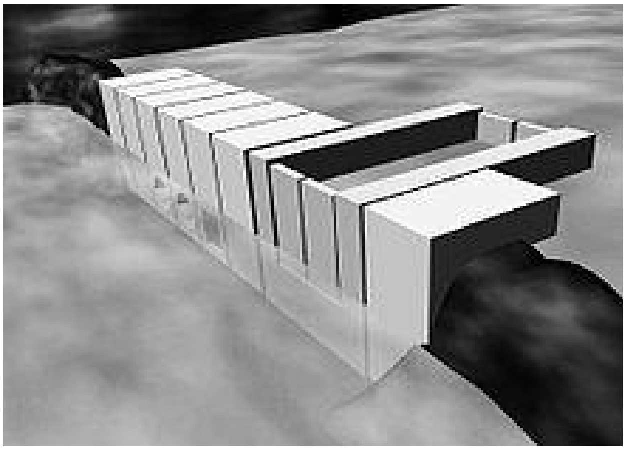

Fig. 2. An artistic impression of a tidal barrage, including embankments, a ship lock and caissons housing a sluice and two turbines.

4.2 Ebb generation

The basin is filled through the sluices until high tide. Then the sluice gates are closed. (At this stage there may be "Pumping" to raise the level further). The turbine gates are kept closed until the sea level falls to create sufficient head across the barrage, and then are opened so that the turbines generate until the head is again low. Then the sluices are opened, turbines disconnected and the basin is filled again. The cycle repeats itself. Ebb generation (also known as outflow generation) takes its name because generation occurs as the tide changes tidal direction.

4.3 Flood generation

The basin is filled through the turbines, which generate at tide flood. This is generally much less efficient than ebb generation, because the volume contained in the upper half of the basin (which is where ebb generation operates) is greater than the volume of the lower half (filled first during flood generation). Therefore the available level difference — important for the turbine power produced — between the basin side and the sea side of the barrage, reduces more quickly than it would in ebb generation. Rivers flowing into the basin may further reduce the energy potential, instead of enhancing it as in ebb generation. Of course this is not a problem with the "lagoon" model, without river inflow.

4.4 Pumping

Turbines are able to be powered in reverse by excess energy in the grid to increase the water level in the basin at high tide (for ebb generation). This energy is more than returned during generation, because power output is strongly related to the head. If water is raised 2 ft (61 cm) by pumping on a high tide of 10 ft (3 m), this will have been raised by 12 ft (3.7 m) at low tide. The cost of a 2 ft rise is returned by the benefits of a 12 ft rise. This is since the correlation between the potential energy is not a linear relationship, rather, is related by the square of the tidal height variation.

4.5 Two-basin schemes

Another form of energy barrage configuration is that of the dual basin type. With two basins, one is filled at high tide and the other is emptied at low tide. Turbines are placed between the basins. Two-basin schemes offer advantages over normal schemes in that generation time can be adjusted with high flexibility and it is also possible to generate almost continuously. In normal estuarine situations, however, twobasin schemes are very expensive to construct due to the cost of the extra length of barrage. There are some favorable geography, however, which are well suited to this type of scheme.

4.6 Tidal lagoon power

Tidal pools are independent enclosing barrages built on high level tidal estuary land that trap the high water and release it to generate power, single pool, around 3.3W/m2. Two lagoons operating at different time intervals can guarantee continuous power output, around 4.5W/m2. Enhanced pumped storage tidal series of lagoons raises the water level higher than the high tide, and uses intermittent renewable for pumping, around 7.5W/m2 i.e. 10 x 10 km delivers 750MW constant output 24/7. These independent barrages do not block the flow of the river and are a viable alternative to the Severn Barrage.

4.7 Energy calculations

The energy available from a barrage is dependent on the volume of water. The potential energy contained in a volume of water is:

$$E = \frac{1}{2} A \rho g h^2$$

Where:
h is the vertical tidal range,
A is the horizontal area of the barrage basin,
ρ is the density of water = 1025 kg per cubic meter (seawater varies between 1021 and 1030 kg per cubic meter) and g is the acceleration due to the Earth's gravity = 9.81 meters per second squared.

The factor is half due to the fact that the basin flows empty through the turbines; the hydraulic head over the dam reduces. The maximum head is only available at the moment of low water, assuming the high water level is still present in the basin.

4.8 Example calculation of tidal power generation

Assumptions:

Let us assume that the tidal range of tide at a particular place is 32 feet = 10 m (approx)

The surface of the tidal energy harnessing plant is 9 km² (3 km × 3 km) = 3000 m × 3000 m = 9 × 106 m2

Density of sea water = 1025.18 kg / m^3

Mass of the sea water = volume of sea water × density of sea water

= (area × tidal range) of water × mass density

= (9 × 10^6 m^2 × 10 m) × 1025.18 kg / m^3

= 92 × 10^9 kg (approx)

Potential energy content of the water in the basin at high tide =

½ × area × density × gravitational acceleration × tidal range squared

= ½ × 9 × 10^6 m^2 × 1025 kg / m^3 × 9.81 m / s^2 × (10 m)^2

=4.5 × 10^{12} J (approx)

Now we have 2 high tides and 2 low tides every day. At low tide the potential energy is zero.

Therefore the total energy potential per day = Energy for a single high tide × 2

= 4.5 × 10^{12} J × 2

= 9 × 10^{12} J

Therefore, the mean power generation potential = Energy generation potential / time in 1 day

= 9 × 1012 J / 86400 s

= 104 MW

Assuming the power conversion efficiency to be 30%: The daily-average power generated = 104 MW * 30% / 100%

= 31 MW (approx)

Because the available power varies with the square of the tidal range, a barrage is best placed in a location with very high-amplitude tides. Suitable locations are found in Russia, USA, Canada, Australia, Korea, and the UK. Amplitudes of up to 17 m (56 ft) occur for example in the Bay of Fundy, where tidal resonance amplifies the tidal range.

5 DYNAMIC TIDAL POWER

Dynamic tidal power or DTP is a new and untested method of tidal power generation. It would involve creating large damlike structure extending from the coast straight to the ocean, with a perpendicular barrier at the far end, forming a large 'T' shape. This long T-dam would interfere with coast-parallel oscillating tidal waves which run along the coasts of continental shelves, containing powerful hydraulic currents

5.1 Description

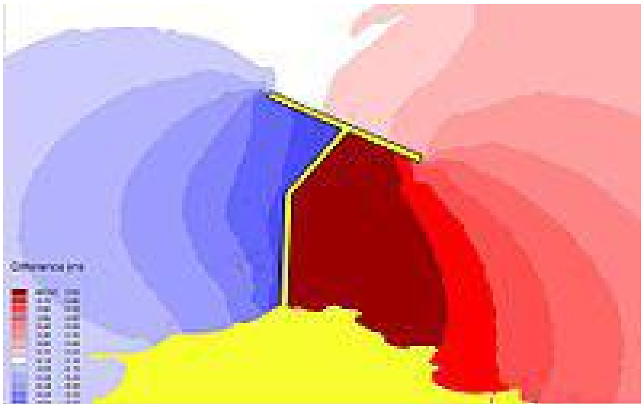

Fig. 3. Top-down view of a DTP dam. Blue and dark red colors indicate low and high tides, respectively.

A DTP dam is a long dam of 30 to 60 km which is built perpendicular to the coast, running straight out into the ocean, without enclosing an area. The horizontal acceleration of the tides is blocked by the dam. In many coastal areas the main tidal movement runs parallel to the coast: the entire mass of the ocean water accelerates in one direction, and later in the day back the other way. A DTP dam is long enough to exert an influence on the horizontal tidal movement, which generates a water level differential (head) over both sides of the dam. The head can be converted into power using a long series of conventional low-head turbines installed in the dam.

5.2Benefits

A single dam can accommodate over 8 GW (8000 MW) of installed capacity, with a capacity factor of about 30%, for an estimated annual power production of each dam of about 23 billion kWh (83 PJ/yr). To put this number in perspective, an average European person consumes about 6800 kWh per year, so one DTP dam could supply energy for about 3.4 million Europeans. If two dams are installed at the right distance from one another (about 200 km apart), they can complement one another to level the output (one dam is at full output when the other is not generating power). Dynamic tidal power doesn't require a very high natural tidal range, so more sites are available and the total availability of power is very high in countries with suitable conditions, such as Korea, China, and the UK (the total amount of available power in China is estimated at 80 - 150 GW).

5.3Challenges

A major challenge is that a demonstration project would yield almost no power, even at a dam length of 1 km or so, because the power generation capacity increases as the square of the dam length (both head and volume increase in a more or less linear manner for increased dam length, resulting in a quadratic increase in power generation). Economic viability is estimated to be reached for dam lengths of about 30 km. Other concerns include:

shipping routes, marine ecology, sediments, and storm surges. Amidst the great number of challenges and few environmental impacts the method of utilizing tidal power to generate electricity has great potential and is certainly a technology most of the countries will try to harness in near future.

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