

Tidal Power Energy

Renewable Energy in Future



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Introduction

It's a plain fact that we are in a world where almost 80 percent of the demanding energy is furnished by sources such as natural gas, coal, or oil, which are quickly being depleted as well as being environmentally unfriendly. We have also developed some destructive processes such as the nuclear power plants, which would also be a sword of Damocles of all human beings. Luckily, we have already realized the importance of making an enormous change in our way of life and our way of using the energy, so looking for renewable resources to substitute current ones is much urgent for us. Tidal power is classified as a renewable energy source, because tides are caused by the orbital mechanics of the solar system and are considered inexhaustible within a human timeframe. Energy from tidal power is also a form of pollution free energy, which has a lot of potential. Though these potentials have not been fully realised yet, we can't deny the advantage of such kind of a renewable energy. This

paper gives some basic introductions of tidal power and the basic principle of how tidal generator works, and it also focuses on the development of tidal power energy of the world.

Background

As we all know that, Electricity and heat energy are essential in our life. However, most of them come from traditional sources of energy such as coal, oil, gas and nuclear power. The extraction and use of these fuels are causing many environmental problems of the world, such as climate change, the ozone layer destruction and so forth. The combustion of fossil fuels created an excess of carbon dioxide, Scientist across the world agrees that we must reduce our use of fossil fuels in the years to come, or we will create devastating effects in nature. An acceptable power generation technology must be mechanically sound, environmentally acceptable, and economically profitable in order to become a real alternative for builders of new capacity. An energy policy for a sustainable future will be based on a high level of energy efficiency and greater use of renewable energy, preferably in an energy mix. I choose tidal power as my target is because it is such the renewable energy source by which we can solve the serious problems: it produces no waste and pollution, what is more important, it is totally free to use. It is absolutely possible that tidal power will be one of the most popular sources of power in future and become an attractive option for power companies looking for renewable source power, but unwilling to accept the risks involved in experimenting with unproven technologies. China is the country that has built the most tidal power stations in the world, and tidal power energy is no doubt playing a more and more important role in China's energy consumption process.

History

Tidal energy is one of the oldest forms of energy used by humans. Indeed, tide mills, in use on the Spanish, French and British coasts, date back to 787 A.D. but it is likely that there were predecessors lost in the anonymity of prehistory. Tide mills consisted of a storage pond, filled by the incoming (flood) tide through a sluice and emptied during the outgoing (ebb) tide through a water wheel. The tides turned waterwheels, producing mechanical power to mill grain and power was available for about two to three hours, usually twice a day.

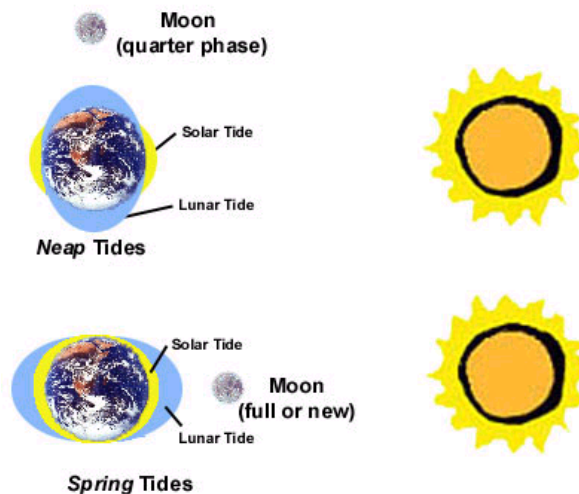
The power requirements of the industrialized world dwarf the output of the early tidal barrages and it was not until the 1960's that the first commercial-scale modern-era tidal power plant was built, near St. Malo, France. The hydro mechanical devices such as the paddlewheel and the overshot waterwheel have given way to highly-efficient

bulb-type hydroelectric turbine/generator sets. The tidal barrage at St. Malo uses twenty-four 10-megawatt low-head bulb-type turbine generator sets. Installed in 1965, the barrage has been functioning without missing a tide for more than 37 years.

After that, more and more commercial-scale tidal barrage was put in service in France, Canada, Switzerland, UK, China and so forth.

Why there are tides

Tides are caused principally by the gravitational pull of the moon on the world's oceans. The sun also plays a minor role, not through its radiant energy but in the form of its gravitational pull, which exerts small additional effect on tidal rhythms. And the rotation of the earth is also a factor in the production of tides. (Figure 1)



(Figure 1: <http://wwwphys.murdoch.edu.au/rise/reslab/resfiles/tidal>)

The resource of tides

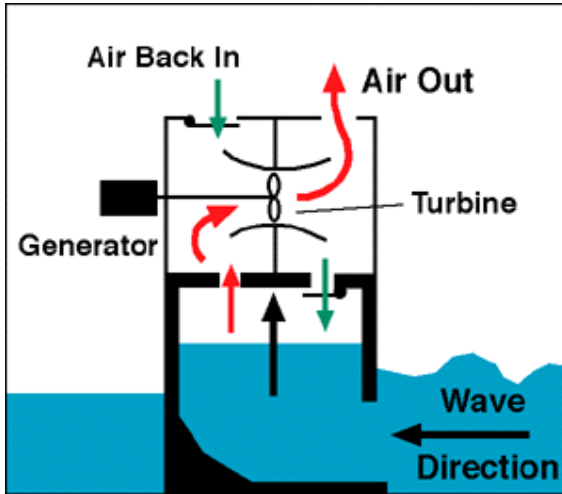
Tidal cycles are calculated using harmonic constants defined by the rhythmic movements of the sun, moon, and earth. The earth is spinning, precessing, and pulsating in concert with its celestial neighbors in an ever-changing and infinite series of movements that causes the oceans to rise and fall. This complex pattern has been closely observed for eons and is now known and mathematically predictable, down to the finest detail across the broadest reaches of time. It is possible, if it strikes one's fancy, to know the precise tidal level at a specific location at a specific moment 100 years or 1000 years in the future. Wind and weather cause changes under extreme conditions ("tidal surges") and these events are not specifically predictable, but the basic harmonic changes in water levels caused by the tides are eminently predictable.

On a global scope, the tides are meters high bulge in the level of the ocean that moves across the globe every 24 hours and 50 minutes. As this bulge nears land, it is changed in amplitude by the decreasing depth and anomalies of the seabed. At the extremes, some tidal ranges are as small as 6 inches and some are as large as 60 feet. Broad-mouthed estuaries create the largest tidal ranges and long straight coastlines tend to have the smallest. The power available (per unit area) in any specific location is a function of the square of the tidal range and thus the largest tidal ranges are the most attractive areas for tidal power generation. The amount of water available in an offshore tidal power generator is a function of the area of seabed impounded. It is most economical to build an impoundment structure in a shallow area, so it follows that the most attractive sites for offshore tidal power generation are those where the tidal range is high and there are broad tidal flats at minimal depth.

How it works

The rise and fall of the sea level can power electric-generating equipment. The gearing of the equipment is tremendous to turn the very slow motion of the tide into enough displacement to produce energy. Tidal barrages, built across suitable estuaries, are designed to extract energy from the rise and fall of the tides, using turbines located in water passages in the barrages. The potential energy, due to the difference in water levels across the barrages, is converted into kinetic energy in the form of fast moving water passing through the turbines. This, in turn, is converted into rotational kinetic energy by the blades of the turbine, the spinning turbine then driving a generator to produce electricity. The diagram demonstrates power generation cycle of a tidal power.

The highest output is achieved from hydroelectric turbines by operating when the available head is highest. The available head is highest at extreme low tide and extreme high tide. These periods are roughly two hours in length, but there is relatively little change in water level during the half hour preceding and the half hour after each of the extreme lows and highs. By including these 30-minute “shoulder” periods, a 3-hour generation period is achieved twice per tidal cycle. Thus, one can effectively generate at optimum levels for roughly half of each tidal cycle. Unfortunately, tidal cycles do not correspond to daily cycles of demand for electricity.



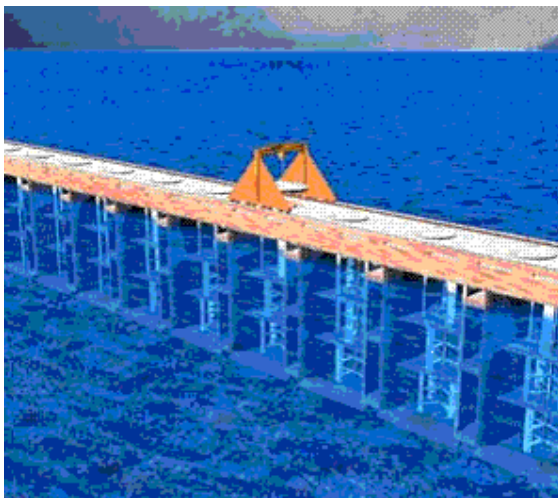
(figure 2)

(<http://home.clara.net/darvill/altenerg/tidal.htm#intro>)

The keys of tidal power technologies

Barrage or dam

A barrage or dam is typically used to convert tidal energy into electricity by forcing the water through turbines, activating a generator. The basic components of a barrage are turbines, sluice gates and, usually, slip locks, all linked to the shore with embankments. When the tides produce an adequate difference in the level of the water on opposite sides of the dam, the sluice gates are opened. The water then flows through the turbines. The turbines turn an electric generator to produce electricity.

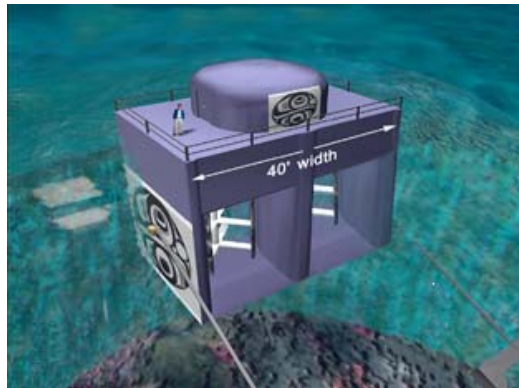


(Figure 3 Tidal fence: <http://www.newint.org/issue335/shifting.htm>)

Tidal fences look like giant turnstiles. They can reach across channels between small islands or across straits between the mainland and an island. The turnstiles spin via tidal currents typical of coastal waters. Some of these currents run at 5–8 knots (5.6–9

miles per hour) and generate as much energy as winds of much higher velocity. Because seawater has a much higher density than air, ocean currents carry significantly more energy than air currents (wind).

Tidal fences are composed of individual, vertical axis turbines which are mounted within the fence structure, known as a caisson, and they can be thought of as giant turn styles which completely block a channel, forcing all of the water through them as shown in figure 4.



(Figure 4 model of a tidal fence www.bluenergy.com/davishydroturbine.html)

Unlike barrage tidal power stations, tidal fences can also be used in unconfined basins, such as in the channel between the mainland and a nearby off shore island, or between two islands. As a result, tidal fences have much less impact on the environment, as they do not require flooding of the basin and are significantly cheaper to install. Tidal fences also have the advantage of being able to generate electricity once the initial modules are installed, rather than after complete installation as in the case of barrage technologies.

Tidal fences are not free of environmental as a caisson structure is still required, which can disrupt the movement of large marine animals and shipping.

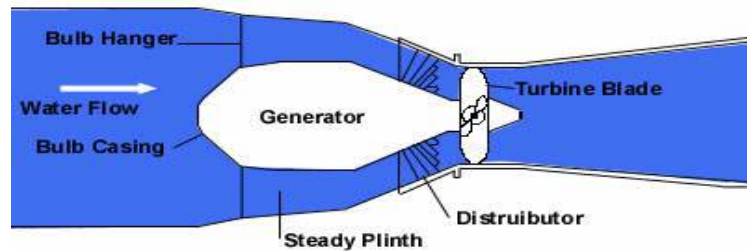
A 2.2GW_p tidal fence using the Davis turbine, is being planned for the San Bernadino Strait in the Philippines. The project, estimated to cost \$US 2.8 Billion and take 6 years to complete.

Tidal turbine

Tidal turbines look like wind turbines. They are arrayed underwater in rows, as in some wind farms. The turbines function best where coastal currents run at between 3.6 and 4.9 knots (4 and 5.5 mph). In currents of that speed, a 15-meter (49.2-foot) diameter tidal turbine can generate as much energy as a 60-meter (197-foot) diameter wind turbine. Ideal locations for tidal turbine farms are close to shore in water depths of 20–30 meters (65.5–98.5 feet).

There are different types of turbines that are available for use in a tidal barrage.

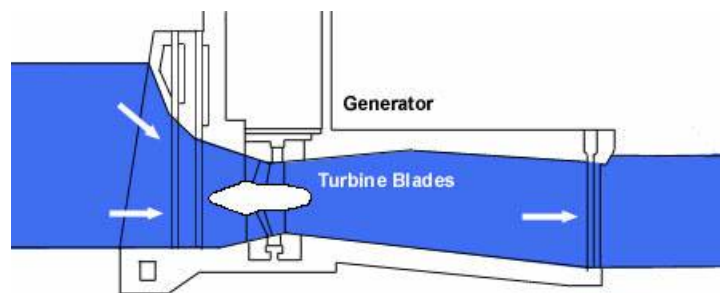
A bulb turbine is one in which water flows around the turbine. If maintenance is required then the water must be stopped which causes a problem and is time consuming with possible loss of generation. The La Rance tidal plant near St Malo on the Brittany coast in France uses a bulb turbine. (Figure 5)



(Figure 5) Bulb Turbine

(<http://wwwphys.murdoch.edu.au/rise/reslab/resfiles/tidal/text.html>)

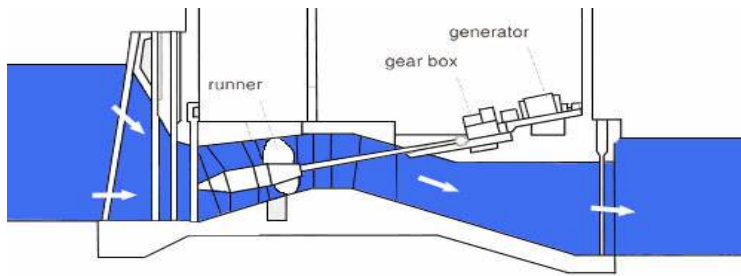
When rim turbines are used, the generator is mounted at right angles to the turbine blades, making access easier. But this type of turbine is not suitable for pumping and it is difficult to regulate its performance. One example is the Straflo turbine used at Annapolis Royal in Nova Scotia. (Figure 6)



(Figure 6) Rim Turbine

(<http://wwwphys.murdoch.edu.au/rise/reslab/resfiles/tidal/text.html>)

Tubular turbines (Figure 7) have been proposed for the UK's most promising site, The Severn Estuary, the blades of this turbine are connected to a long shaft and are orientated at an angle so that the generator is sitting on top of the barrage. The environmental and ecological effects of tidal barrages have halted any progress with this technology and there are only a few commercially operating plants in the world, one of these is the La Rance barrage in France.



(Figure 7) Tubular Turbine

<http://wwwphys.murdoch.edu.au/rise/reslab/resfiles/tidal/text.html>

Category of generation

Ebb generation

The basin is filled through the sluices and freewheeling turbines until high tide. Then the sluice gates and turbine gates are closed. They are kept closed until the sea level falls to create sufficient head across the barrage and 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 ebbs.

Flood generation

The basin is emptied through the sluices and turbines 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 (the domain of Flood generation).

Two-way generation

Generation occurs both as the tide ebbs and floods. This mode is only comparable to Ebb generation at spring tides, and in general is less efficient. Turbines designed to operate in both directions are less efficient.

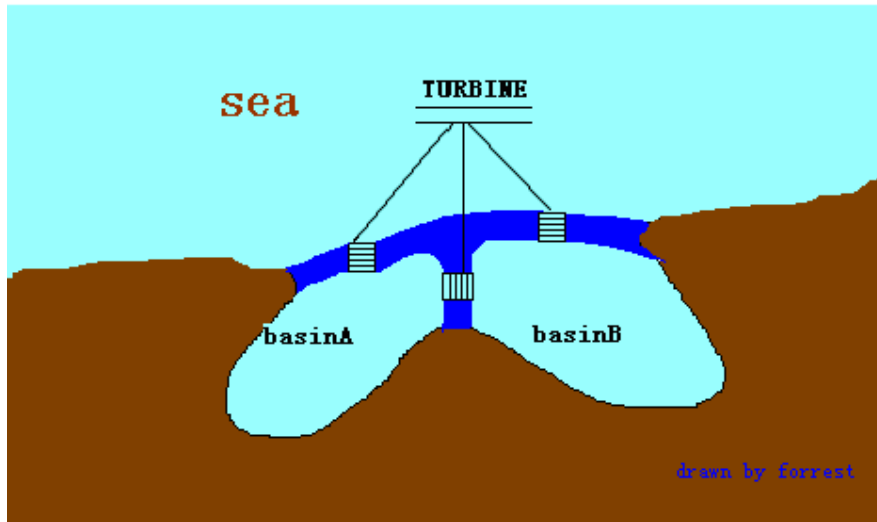
Pumping

Turbines can be powered in reverse by excess energy in the grid to increase the water level in the basin at high tide (for Ebb generation and two-way generation). This energy is returned during generation.

Two-basin schemes

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, two-basin schemes are very expensive to construct due to the cost of the extra length.



(Figure 8) Schematic diagram of two basin tidal power station

Simulation Model

The tidal cycle and the performance characteristics of low-head hydroelectric generating equipment are known. By combining these two known sets of parameters, we can simulate the output from a tidal power plant and model a variety of configurations with accuracy and detail. Following is a description of the simulation model used by the author and created by John Haapala of Harza Engineering (now Montgomery Watson Harza Engineering).

The model determines tide levels at 6-minute intervals for any day, month, or year for the period of years between 1949 and 2025. The tide levels are predicted from a series of harmonic equations as provided in a FORTRAN program developed by NOAA, in the case of US sites or by the British Admiralty, in the case of British sites. Predicted tide levels may vary from actual tide levels due to weather conditions such as wind and atmospheric pressure. A comparison of tide levels predicted by the model and actual recorded tide levels showed agreement well within acceptable limits for a feasibility study. The constantly changing tidal regime would cause generation to vary by several percent from year to year. Other things being equal, it was found that during a high generation year (1998) project output would be about 8% greater than in a low generation year (2005). This cycle is known as the nodal cycle.

A hypothetical equipment package is selected and its operating parameters are input

and an impoundment size is selected, which defines the amount and timing of water available and the sequence of heads available. Together, these parameters determine the turbine flow and efficiency as well as the generator efficiency. Because the turbines have minimal heads, there are periods of sluicing that are essential to the operation in order to maximize or minimize the water levels in the pool in preparation for the next generation cycle. Some of the sluicing flows through the turbines and sluice gates provide addition sluicing capacity.

Sluicing is determined from the following equation: $Q = C * A * (2g * H)^{1/2}$

Where:

Q is the sluice flow in cfs

C is the sluice gate coefficient or turbine sluicing coefficient

A is the sluice gate area (ft²) or turbine area for sluicing (ft²)

H is the head on the sluice (feet)

g is 32.2 ft/sec²

The net energy is determined by using the following formula:

$$E = 0.08464 * Q * H * E_t * E_g * E_{tr} * L_t * L_{su} * L_o * T$$

Where:

E is the energy generation in kilowatt-hours

Q is the turbine flow in cfs

H is the net head on the turbine in feet

E_t is the turbine efficiency

E_g is the generator efficiency

E_{tr} is the transformer efficiency

L_t is the transmission line loss factor

L_{su} is the station use loss factor

L_o is the forced and unforced outage loss factor

T is the time increment (0.1 hour in the model)

Hydraulic losses unavoidably occur near the intake and outlet of a turbine. These head losses are included based on the following equation: $HL = k * Q^2$

Where:

HL is the head loss in feet

k is the head loss coefficient

Q is the turbine flow in cfs

Transmission line losses are included to the point of interconnection where the sale of electricity is metered. Some electricity use normally occurs at the project site, which is accounted for in the station use factor. The forced outage loss factor should account for average outages of all types over the economic life of the project. Outage losses would include factors such as transmission line forced outages, and down time for equipment repair, both scheduled and unscheduled.

Energy conversion

Moving water has kinetic energy similar to wind. The energy per second intercepted by a device of frontal area $A_0(\text{m}^2)$ in water of density ρ , and current velocity V (m/s) is therefore given by:

$$P_g(t) = 0.5\rho A_0 V^3(t)$$

The power that can be converted to a useable mechanical form is limited for a device in an open water flow to:

$$P_m(t) = 0.5C_p \rho A_0 V^3(t)$$

Where C_p is the power coefficient. The value of C_p for a turbine exposed to the flow of an incompressible fluid is limited to a theoretical maximum value of approximately 0.593 according to Betz law. For a device the power coefficient is generally a function of the tip speed ratio (ratio between the speed of the turbine blade tip and the fluid flow speed), which is dependent on the blade form and the number of the blades.

Assuming a gearbox transmission efficiency of η_1 and generator efficiency of η_2 then the electrical power output is given as:

$$P(t) = \eta_1 \eta_2 0.5C_p \rho A_0 V^3(t)$$

Tidal currents are not constant. Generally they are a combination of quasi-steady marine currents and flows induced by the tides. Estimation of energy capture therefore becomes a fairly complex procedure. However for most sites the flows are purely tidal, making it possible to parameterize the tidal currents as series of simple sinusoids. Assuming the current velocity $V(t)$ follows a cyclic pattern then:

$$V(t) = V_{\max} \sin \omega t$$

$$\omega = \frac{2\pi}{T}$$

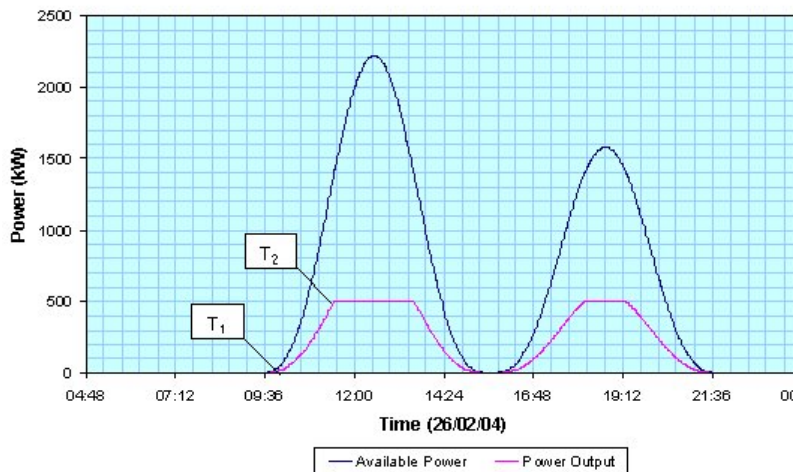
V_{\max} is the maximum current speed at the surface

ω is the angular velocity of the tide

T is the period of the cycle, typically 12h 25 min or 745 minutes.

The graph below shows the power available and the predicted power output of a marine current turbine over a typical cycle. The turbine power coefficient was assumed to be 0.4, a cut-in speed of 0.7 m/s (14 kW) was imposed, and rated speed of 2.4 m/s, thereby limiting the maximum power (rated) to a value of 500 kW. Given the predictable nature of tidal flows, it should not be necessary to set a cut-out condition for the turbine during normal operation.

The times at which cut-in and rated power occur (relative to the start of the cycle) are indicated by T1 and T2 in below



(http://www.esru.strath.ac.uk/EandE/Web_sites/03-04/marine/energy_theory.htm)

A tidal current turbine will normally generate power for both flow (flood and ebb) directions, so its power characteristic (as a function of time) will be similar for each half of the cycle, however the speeds for the flood flow are generally higher than that for the ebb flow.

The energy captured given by the area is under the power curve. So the energy captured during one half of each half tidal cycle is:

$$\int P(t) dt = \int_{T_1}^{T_2} (\eta_1 \eta_2 0.5 C_p \rho A_0 V_{\max}^3 \sin^3 \omega t) dt + P_{\text{rated}} (T_m - T_2)$$

Advantage of tidal power energy

1. Renewable resource, it needs no fuel to maintain, and free of charge
2. Totally no pollution, unlike fossil fuels, it produces no greenhouse gases or other waste.

3. Predictable source of energy (compared with wind and solar), it is independent of weather and climate change and follows the predictable relationship of the lunar orbit
4. More efficient than wind because of the density of water
5. It will protect a large stretch of coastline against damage from high storm tides

Disadvantage of tidal power energy

1. Presently costly, very expensive to build and maintain (A 1085MW facility could cost about 1.2 billion dollars to construct and run)
2. Barrage has environmental affects
 - a) fish and plant migration
 - b) Silt and mud deposits
 - c) Waste and sewage blocks
3. Technology is not fully developed
4. Only provides power for around 10 hours each day, when the tide is actually moving in or out

Representative tidal projects of the world

La Rance:



The first tidal power plant (average tidal range 8 metres) was completed at the mouth of the La Rance estuary on the Brittany coast of France in 1966. This 240 MW plant has been working successfully ever since and meets the needs of the equivalent of a city of 300,000 people. It was intended to be the first of a series of French tidal power plants, but during the 1960s the French power generation strategy shifted in

favour of nuclear power and no more tidal plants have been built.

This barrage uses Bulb Turbines, which were developed by Electricite de France. This allows generation on both ebbs of the tide. These axial flow turbines were also designed to pump water into the basin for the purposes described earlier. This makes it easier to anticipate generation levels. This type of turbine is popular with Hydropower and has been used on mainland Europe in dams on the Rhine and Rhone rivers.

(<http://www.phys.murdoch.edu.au/rise/reslab/resfiles/tidal/text.html>)

Annapolis Royal:

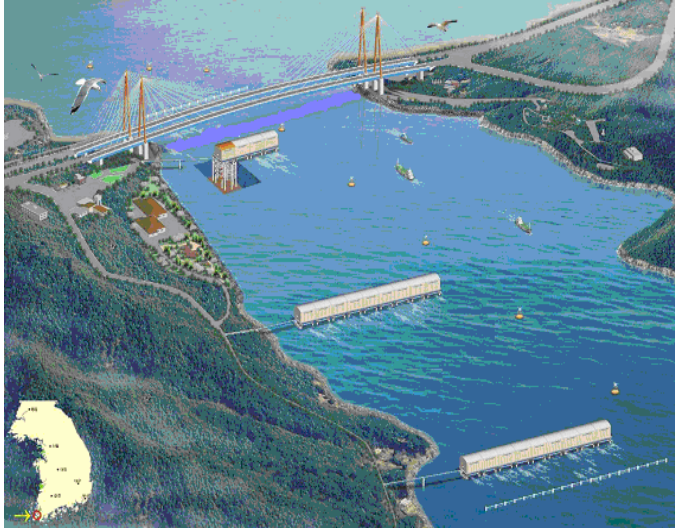


The Annapolis Tidal Generating Station, located in Annapolis Royal and completed in 1984, was a pilot project sponsored by the provincial and federal governments to explore the potential of harnessing energy from the world record tidal range of the Bay of Fundy.

(http://www.carmenanddaniel.com/Maritime/index_7.htm)

The 20 MW Annapolis station is one of only three tidal power plants in the world and the only modern tidal plant in North America. The station uses the world's largest straflo turbine to produce more than 30 million kilowatt hours per year – enough to power 4,000 homes. The plant produces power twice a day depending on the tidal cycle.

Jiangxia power station



Jiangxia power station is the largest tidal power station in China and the third largest tidal power station in the world, which has been put into operation for nearly 20 years. The project investment was 1,130 million Yuan. It has started the construction from 1974. The first generator sets of 500kW started its generation in 1980. The project was

http://www.knrec.or.kr/upload/product/20060303111413_1.jpg completed in 1985, which was installed one set generator of 500kW, one set of 600kW and 3 sets of 700kW with the total capacity of 3.2MW. The power station belongs to single-reservoir and two-function type, with which the area of reservoir is $1.58 \times 10^6 \text{m}^2$, and it was designed to generate $10.7 \times 10^7 \text{kWh}$ yearly. In 1996, the annual net generating capacity was 5.0210^6kWh , equaling half capacity of the design. The main reason is that it has difference between the design state and the actual state of the operation. Furthermore, the operation guarantee of the sets and operation control method should be upgraded. But general speaking, Jiangxia power station is successful which provides more comprehensive technology for construction of tidal power station in China, and as well as accumulates abundant experience for operation, management and multi enterprise of tidal power station.

There are many operating tidal power plants in the world, following table shows some huge ones:

Country	Place	Mean tidal range (m)	Area of basin (km ²)	Maximum capacity (MW)
Argentina	San Jose	5.9	-	6800
Australia	Secure Bay	10.9	-	?
Canada	Cobequid	12.4	240	5338

	Cumberland	10.9	90	1400
	Shepody	10.0	115	1800
	Kutch	5.3	170	900
India	Cambay	6.8	1970	7000
	Garolim	4.7	100	480
Korea	Cheonsu	4.5	-	-
	Rio Colorado	6-7	-	?
Mexico	Tiburón	-	-	?
	Severn	15.0	520	8640
	Mersey	6.5	61	700
United Kingdom	Wyre	6.0	5.8	47
	Conwy	5.2	5.5	33
	Passamaquoddy Bay	5.5	-	?
United States	Knik Arm	7.5	-	2900
	Turnagain Arm	7.5	-	6500
Russia	Mezen	9.1	2300	15000

	Tugur	-	-	10000 or 7000
	Penzhinskaya Bay	6.0	-	50000
South Africa	Mozambique Channel	?	?	?

<http://wwwphys.murdoch.edu.au/rise/reslab/resfiles/tidal/text.html>

Social attitude to tidal power energy

The social attitude is closely connected with the environmental impacts, the financial factors and the application efficiency.

The environmental concern is especially related to the impacts on fish and plant migration, some studies that have been undertaken to date to identify the environmental impacts of a tidal power scheme have determined that each specific site is different and the impacts depend greatly upon local geography, Local tides changed only slightly due to the La Rance barrage, and the environmental impact has been negligible, but this may not be the case for all other sites, we still need information to prove that; when refer to silt and mud deposits, the barrage could have a compensating impact on the level of silt and sediment suspended in the water. The waters in the Severn Estuary currently carry in suspension much silt churned up by the tides, making the water impenetrable to sunlight. With the barrage in place and the tidal ebbs and flows reduced, some of this silt would drop out, making the water clearer.

Regarding to the financial factor, currently, The long construction period for the larger schemes and low load factors would result in high unit costs of energy, which makes tidal projects have relatively high capital cost in relation to the usable output, compared with most other types of power plant, consequently with long capital payback times and low rates of return on the capital invested. Predicted unit costs of generation are therefore unlikely to change and currently remain uncompetitive with conventional fossil-fuel alternatives. However, Some non-energy benefits would stem from the development of tidal energy, which would yield a relatively minor monetary value in proportion to the total scheme cost. These benefits are difficult to quantify accurately and may not necessarily accrue to the barrage developer. Employment opportunities would be substantial at the height of construction, with the creation of some permanent long-term employment from associated regional economic

development. Public opinion focuses more and more on these non-energy benefits and that would be an important force for the development of the tidal power energy.

Tidal power generators use familiar and reliable low-head hydroelectric generating equipment, conventional marine construction techniques, and standard power transmission methods. The key points in determining the application efficiency of a tidal power plant are the size (length and height) of the barrage required, and the difference in height between high and low tides. Although the technology is not developing in a very fast rate, we have gained a lot of experience. According to the high capital cost for a tidal energy project, the electricity cost is very sensitive to the discount rate. Therefore, how to prove the tidal power energy is not a waste of money is what we need to do emergently.

The role that public opinion plays should not be forgotten at any time; a very important difference between the countries where some renewable but costly energy has become widespread is largely depending on the public support. A sustainable Future can only be established if the reasons behind decisions are public knowledge and the possible dangers are researched well.

Conclusion & discussion

Comparing with wind power energy and solar energy, tidal power seems not a big sustainable resource, but it is doing a fast-rate progress in recent decades. I can see a bright future of the tidal power and wave power (we can call them ocean energy) when we fix several problems. First we have to make the cost lower, so that it can be built in a large scale, hopefully, within six years of operation, the Blue Energy system will generate electricity at a competitive rate of \$US 0.04 per kWh, constantly trending downward; Secondly, the turbine has to be more effective, technology of its working process should be fully developed; the point with tidal power energy is that, we should never neglect the environment impacts of tidal power, we do need a way to solve the current problems.

Reference, photos and figures

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