Tidal stream generator

A **tidal stream generator,** often referred to as a **tidal energy converter (TEC)** is a machine that extracts energy from moving masses of water, in particular tides, although the term is often used in reference to machines designed to extract energy from run of river or tidal estuarine sites. Certain types of these machines function very much like underwater wind turbines, and are thus often referred to as **tidal turbines**. They were first conceived in the 1970s during the oil crisis.[1]

Evopod - A semi-submerged floating approach tested in Strangford Lough.

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

Similarity to wind turbines

Tidal stream generators draw energy from water currents in much the same way as wind turbines draw energy from air currents. However, the potential for power generation by an individual tidal turbine can be greater than that of similarly rated wind energy turbine. The higher density of water relative to air (water is about 800 times the density of air) means that a single generator can provide significant power at low tidal flow velocities compared with similar wind speed.[2] Given that power varies with the density of medium and the cube of velocity, water speeds of nearly one-tenth the speed of wind provide the same power for the same size of turbine system; however this limits the application in practice to places where the tide moves at speeds of at least 2 knots (1 m/s) even close to neap tides. Furthermore, at higher speeds in a flow between 2 to 3 metres per second in seawater a tidal turbine can typically access four times as much energy per rotor swept area as a similarly rated power wind turbine.

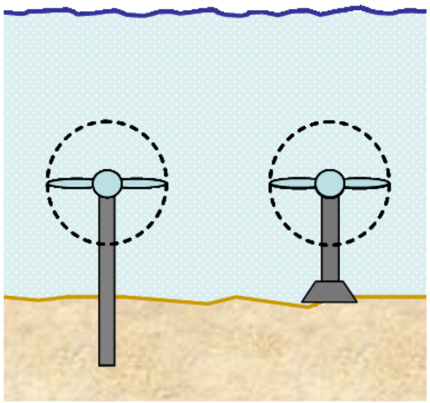
Types of tidal stream generators

Since tidal stream generators are an immature technology, no standard technology has yet emerged as the clear winner, but a large variety 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.

The European Marine Energy Centre recognizes six principal types of tidal energy converter. They are horizontal axis turbines, vertical axis turbines, oscillating hydrofoils, venturi devices, Archimedes Screw, tidal kite.

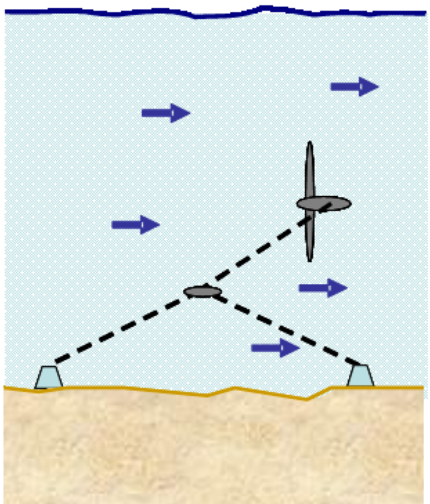
Axial turbines

These are close in concept to traditional windmills operating under the sea and have the most prototypes currently operating. These include:



Bottom-mounted axial turbines

The AR-1000, a 1MW tidal turbine developed by Atlantis Resources Corporation which was successfully deployed and commissioned at the EMEC facility during the summer of 2011. The AR series turbines are commercial scale Horizontal Axis Turbines designed for open ocean deployment in the harshest environments on the planet. AR turbines feature a single rotor set with highly efficient fixed pitch blades. The AR turbine is rotated as required with each tidal exchange. This is done in the slack period between tides and fixed in place for the optimal heading for the next tide. AR turbines are rated at 1MW @ 2.65 m/s of water flow velocity.[*citation needed*]



A cable tethered turbine

Kvalsund, south of Hammerfest, Norway. Although still a prototype, a turbine with a reported capacity of 300 kW was connected to the grid on 13 November 2003.

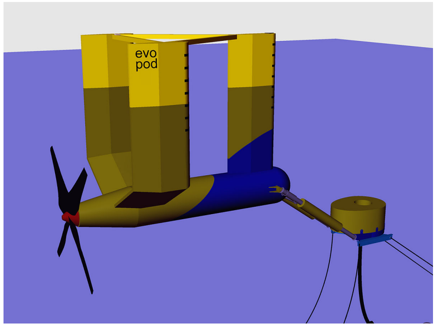
A 300 kW Periodflow marine current propeller type turbine — Seaflow — was installed by Marine Current Turbines off the coast of Lynmouth, Devon, England, in 2003. The 11m diameter turbine generator was fitted to a steel pile which was driven into the seabed. As a prototype, it was connected to a dump load, not to the grid.

Since April 2007 Verdant Power has been running a prototype project in the East River between Queens and Roosevelt Island in New York City; it was the first major tidal-power project in the United States.[3] The strong currents pose challenges to the design: the blades of the 2006 and 2007 prototypes broke off, and new reinforced turbines were installed in September 2008.

Following the Seaflow trial, a full-size prototype, called SeaGen, was installed by Marine Current Turbines in Strangford Lough in Northern Ireland in April 2008. The turbine began to generate at full power of just over 1.2 MW in December 2008 and is reported to have fed 150 kW into the grid for the first time on 17 July 2008, and has now contributed more than a gigawatt hour to consumers in Northern Ireland.[4] It is currently the only commercial scale device to have been installed anywhere in the world. SeaGen is made up of two axial flow rotors, each of which drive a generator. The turbines are capable of generating electricity on both the ebb and flood tides because the rotor blades can pitch through 180˚.[5]

OpenHydro, an Irish company exploiting the Open-Centre Turbine developed in the U.S., has a prototype being tested at the European Marine Energy Centre (EMEC), in Orkney, Scotland.

A prototype semi-submerged floating tethered tidal turbine called Evopod has been tested since June 2008[6] in Strangford Lough, Northern Ireland at 1/10 scale. The company developing it is called Ocean Flow Energy Ltd, and they are based in the UK. The advanced hull form maintains optimum heading into the tidal stream and it is designed to operate in the peak flow of the water column.



A 3D model of an Evopod tidal turbine

In 2010, Tenax Energy of Australia proposed to put 450 turbines off the coast of the Australian city Darwin, in the Clarence Strait. The turbines would feature a rotor section approximately 15 metres in diameter with a gravity base slighter larger than this to support the structure. The turbines would operate in deep water well below shipping channels. Each turbine is forecast to produce energy for between 300 and 400 homes.

Tidalstream, a UK-based company, has commissioned a scaled-down Triton 3 turbine in the Thames. It can be floated out to site, installed without cranes, jack-ups or divers, and then ballasted into operating position. At full scale the Triton 3 in 30-50m deep water has a 3MW capacity, and the Triton 6 in 60-80m water has a capacity of up to 10MW, depending on the flow. Both platforms have man-access capability both in the operating position and in the float-out maintenance position.

Vertical and horizontal axis crossflow turbines

Invented by Georges Darreius in 1923 and patented in 1929, these turbines can be deployed either vertically or horizontally.

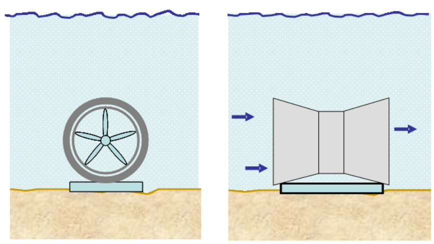
The Gorlov turbine[7] is a variant of the Darrieus design featuring a helical design which is being commercially piloted on a large scale in S. Korea, starting with a 1MW plant that started in May 2009 and expanding to 90MW by 2013. Neptune Renewable Energy has developed Proteus a shrouded vertical axis turbine which can be used to form an array in mainly estuarine conditions. The Musgrove vertical Axis Wind Turbine with vertical self-starting free hinged aerodynamic blades is probably the inspiration for the this turbine.

In April 2008, the Ocean Renewable Power Company, LLC (ORPC) successfully completed the testing of its proprietary turbine-generator unit (TGU) prototype at ORPC's Cobscook Bay and Western Passage tidal sites near Eastport, Maine. The TGU is the core of the OCGen technology and utilizes advanced design cross-flow (ADCF) turbines to drive a permanent magnet generator located between the turbines and mounted on the same shaft. ORPC has developed TGU designs that can be used for generating power from river, tidal and deep water ocean currents.

Trials in the Strait of Messina, Italy, started in 2001 of the Kobold turbine concept.[8]

Flow augmented turbines

Using flow augmentation measures, for example a duct or shroud, the incident power available to a turbine can be increased. The most common example uses a shroud to increase the flow rate through the turbine, which can be of either the axial or crossflow type.


A shrouded turbine

The Australian company Tidal Energy Pty Ltd undertook successful commercial trials of efficient shrouded tidal turbines on the Gold Coast, Queensland in 2002. Tidal Energy has commenced a rollout of their shrouded turbine for a remote Australian community in northern Australia where there are some of the fastest flows ever recorded (11 m/s, 21 knots) – two small turbines will provide 3.5 MW. Another larger 5 meter diameter turbine, capable of 800 kW in 4 m/s of flow, is planned for deployment as a tidal powered desalination showcase near Brisbane Australia in October 2008.

Oscillating devices

Oscillating devices do not have a rotating component, instead making use of aerofoil sections which are pushed sideways by the flow. Oscillating stream power extraction was proven with the omni- or bi-directional Wing'd Pump windmill. During 2003 a 150 kW oscillating hydroplane device, the Stingray, was tested off the Scottish coast. The Stingray uses hydrofoils to create oscillation, which allows it to create hydraulic power. This hydraulic power is then used to power a hydraulic motor, which then turns a generator.

Pulse Tidal operate an oscillating hydrofoil device in the Humber estuary. Having secured funding from the EU, they are developing a commercial scale device to be commissioned 2012.

The bioSTREAM tidal power conversion system, uses the biomimicry of swimming species, such as shark, tuna, and mackerel using their highly efficient Thunniform mode propulsion. It is produced by Australian company BioPower Systems.

A 2 kW prototype relying on the use of two oscillating hydrofoils in a tandem configuration has been developed at Laval University and tested successfully near Quebec City, Canada, in 2009. A hydrodynamic efficiency of 40% has been achieved during the field tests.

Venturi effect

Venturi effect devices use a shroud or duct in order to generate a pressure differential which is used to run a secondary hydraulic circuit which is used to generate power. A device, the Hydro Venturi, is to be tested in San Francisco Bay.

Commercial plans

RWE's npower announced that it is in partnership with Marine Current Turbines to build a tidal farm of SeaGen turbines off the coast of Anglesey in Wales, near the Skerries.[9]

In November 2007, British company Lunar Energy announced that, in conjunction with E.ON, they would be building the world's first deep-sea tidal energy farm off the coast of Pembrokshire in Wales. It will provide electricity for 5,000 homes. Eight underwater turbines, each 25 metres long and 15 metres high, are to be installed on the sea bottom off St David's peninsula. Construction is due to start in the summer of 2008 and the proposed tidal energy turbines, described as "a wind farm under the sea", should be operational by 2010.Wikipedia:Manual of Style/Dates and numbers#Precise language

British Columbia Tidal Energy Corp. plans to deploy at least three 1.2 MW turbines in the Campbell River or in the surrounding coastline of British Columbia by 2009.Wikipedia:Manual of Style/Dates and numbers#Precise language

Alderney Renewable Energy Ltd is planningWikipedia:Manual of Style/Dates and numbers#Chronological items to use tidal turbines to extract power from the notoriously strong tidal races around Alderney in the Channel Islands. It is estimated that up to 3 GW could be extracted. This would not only supply the island's needs but also leave a considerable surplus for export.

Nova Scotia Power has selected OpenHydro's turbine for a tidal energy demonstration project in the Bay of Fundy, Nova Scotia, Canada and Alderney Renewable Energy Ltd for the supply of tidal turbines in the Channel Islands.[10]

Pulse Tidal are designing a commercial deviceWikipedia:Manual of Style/Dates and numbers#Chronological items with seven other companies who are expert in their fields.[11] The consortium was awarded an €8 million EU grant to develop the first device, which will be deployed in 2012Wikipedia:WikiProject Countering systemic bias and generate enough power for 1,000 homes.

ScottishPower Renewables are planning to deploy ten 1MW HS1000 devices designed by Hammerfest Strom in the Sound of Islay.Wikipedia:Manual of Style/Dates and numbers#Chronological items[12]

Energy calculations

Turbine power

Tidal energy converters can have varying modes of operating and therefore varying power output. If the power coefficient of the device " C_P " is known, the equation below can be used to determine the power output of the hydrodynamic subsystem of the machine. This available power cannot exceed that imposed by the Betz limit on the power coefficient, although this can be circumvented to some degree by placing a turbine in a shroud or duct. This works, in essence, by forcing water which would not have flowed through the turbine through the rotor disk. In these situations it is the frontal area of the duct, rather than the turbine, which is used in calculating the power coefficient and therefore the Betz limit still applies to the device as a whole.

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

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

where:

C_P = the turbine power coefficient

P = the power generated (in watts)

ρ = the density of the water (seawater is 1027 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, ducted turbines are capable of as much as 3 to 4 times the power of the same turbine rotor in open flow.[13]

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:[14][15]

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

where

ρ = the density of the water (seawater is 1027 kg/m³)

g = gravitational acceleration (9.80665 m/s^2)

ΔH_{max} = maximum differential water surface elevation across the channel

Q_{max} = maximum volumetric flow rate though the channel.

Potential sites

As with wind power, selection of location is critical for the tidal turbine. Tidal stream systems need to be located in areas with fast currents where natural flows are concentrated between obstructions, for example at the entrances to bays and rivers, around rocky points, headlands, or between islands or other land masses. The following potential sites are under serious consideration:

- Pembrokeshire in Wales[16]
- River Severn between Wales and England[17]
- Cook Strait in New Zealand[18]
- Kaipara Harbour in New Zealand
- Bay of Fundy[19] in Canada.

- East River[20] in the USA
- Golden Gate in the San Francisco Bay[21]
- Piscataqua River in New Hampshire[22]
- The Race of Alderney and The Swinge in the Channel Islands
- The Sound of Islay, between Islay and Jura in Scotland[23]
- Pentland Firth between Caithness and the Orkney Islands, Scotland
- Humboldt County, California in the United States
- Columbia River, Oregon in the United States

Modern advances in turbine technology may eventually see large amounts of power generated from the ocean, especially tidal currents using the tidal stream designs but also from the major thermal current systems such as the Gulf Stream, which is covered by the more general term marine current power. Tidal stream turbines may be arrayed in high-velocity areas where natural tidal current flows are concentrated such as the west and east coasts of Canada, the Strait of Gibraltar, the Bosporus, and numerous sites in Southeast Asia and Australia. Such flows occur almost anywhere where there are entrances to bays and rivers, or between land masses where water currents are concentrated.

Environmental impacts

Very little direct research or observation of tidal stream systems exists. Most direct observations consist of releasing tagged fish upstream of the device(s) and direct observation of mortality or impact on the fish.

One study of the Roosevelt Island Tidal Energy (RITE, Verdant Power) project in the East River (New York City), utilized 24 split beam hydroacoustic sensors (scientific echosounder) to detect and track the movement of fish both upstream and downstream of each of six turbines. The results suggested (1) very few fish using this portion of the river, (2) those fish which did use this area were not using the portion of the river which would subject them to blade strikes, and (3) no evidence of fish traveling through blade areas. [*citation needed*]

Work is currently being conducted by the Northwest National Marine Renewable Energy Center (NNMREC)to explore and establish tools and protocols for assessment of physical and biological conditions and monitor environmental changes associated with tidal energy development.

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