Ocean Power: tidal and wave energy

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The growing necessity of a sustainable energy supply requires a great expansion of renewable energy production. While developing and realizing different concepts of energy usage like photovoltaic, wind, geothermal or biomass energy, another big potential energy source has got very low attention – energy from tidal power. Tidal power allows many ways of electricity production and can be classified into two different main types:

- Tidal stream systems make use of the kinetic energy of moving water to power turbines, in a similar way to windmills that use moving air. This method is gaining in popularity because of the lower cost and lower ecological impact compared to barrages.

- Barrages make use of the potential energy in the difference in height (or head) between high and low tides. Barrages suffer from very high civil infrastructure costs, a worldwide shortage of viable sites, and environmental issues.

Since the economical potential of hydroelectric power plants in Europe is nearly exhausted, this work will be focused on different concepts of tidal barrages, tidal stream and wave generators.

Tidal power stations are a variation of the classical hydroelectric power plants using the level difference of the water between low tide and flood, also called tidal range, for the production of electricity. For this purpose, dams can be established in estuaries or sea bays as a separation from the high seas. Such embankments get notches so that water will stream in when the tide is high and drain off when the tide is out, a process under the driving mechanism of the turbines. In both operation phases electric current is therefore produced. The big advantage of this technology is that low tide and flood continuously alternate and, hence, the tidal force displays a computable and dependable energy source. The potential energy from the resultant tidal range can be calculated as follows:

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

- ρ is the density of seawater (approximately 1025 kg/m³)
- A is the swept area by the rotors (m²)
- g is the gravitational acceleration (9,80665 m/s²)
- h is the difference between ebb and flut(m)

The best known representative of this technology is the tidal power station in the mouth of the river La Rance near Saint-Malo at the French Atlantic coast. It was established already in 1966 and has a tidal range of 12 - 16 m with which a maximum power of 240 MW is reached. The concrete embankment has a length of 750 m and the storage reservoir basin´s magnitudes add up to 22 km in length and, on average, about 1 km in width.

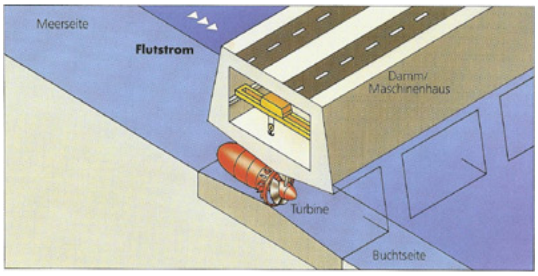

figure 1: water inflow (flood)

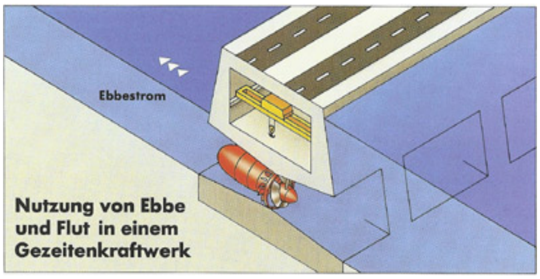

figure 2: water outflow (ebb)

Tidal power stations can only produce electricity at the precise moment of the occurrence of either flood or low tide. When the flood comes, the water streams through the notches in the embankment into the reservoir with the lower water level, making the turbines turn. Being coupled to the turbines, generators are then driven just as well, producing electric current. As soon as the maximum water level is reached, the streaming comes to a standstill and no more electricity is produced before the low tide arrives. During low tide the water from the reservoir runs off again into the ocean, driving the generators once more. The turbines are generally pipe turbines, equipped with adjustable and reversible shovels. This makes it possible that the turbines can work in both streaming phases. Between the flood and the low tide streamings the equipment comes to a brief shutdown in each case. Consequently, a periodically variable amount of power is produced, each streaming period lasts about 12.5 hours. In addition the power, albeit to a minor degree, is influenced by weather conditions like wind or precipitation.

If suitable turbines are installed and the storage basin is big enough, a tidal power station can also be used as a pumping accumulator power station. In this special case the turbines still pump water into the storage basin beyond the reached water level, even if the flood stream has already come to the shutdown. Then, with low tide, more water is blown off and therefore more electricity is produced.

The difficulty of this energy change process lies mainly in the fact that, as a rule, an economic application is only possible from a tidal range of 5 m on. That is why only few locations can be considered. Possible application places for tidal power stations are, for example, in the mouth of the river Severn between Britain and Wales, in Alaska near Anchorage, at the Cambridge Gulf in Western Australia and in the Fundy Bay in Canada. Worldwide there are approximately at least 100 possible locations for those facilities. In Germany the potential is estimated to be very little on account of the relatively low tidal range of about 2 - 3.5 m. Furthermore the tidal power stations are also facing the danger of corrosion, which is clearly higher than in soft water areas. Additionally impurities caused by salt and sediments are problematic because they require a large complexity in the operation management. Finally it must be mentioned that, above all, the establishment of big dams always makes such equipments affect or damage nature, and therefore interferences of the flora and fauna can be the results. Since tidal power stations also have effects on the rhythm of low tide and flood, an adaptation to the changed living conditions becomes necessary for the creatures in that sphere.

figure 3: Tidel turbines (horizontal-axis propeller design)

Alternatively to those tidal power stations which used the tidal range to produce electricity, the first projects are being realised whose technology intends the winning of electricity from sea flows. They are sea flow power stations, resembling the wind power equipments with the difference that the rotor turns underwater and that it is driven by the constant tidal change. A suitable pilot plant was successfully installed already in summer, 2003 near the coast of North Devon in England under the project name "Seaflow". In another step, a new equipment with a power of 1.2 MW originated in April, 2008 near Strangford Lough under the project name "Seagen". The principle of turbines around which the waters are freely circulating has the big advantage that it can be employed in numerous locations and means only low disturbance of the environment. Optimum locations have a water deepness of 15 - 20 m and streaming speeds of at least 2 - 3 m/s in the streaming maximum with the steadiest course possible.

The power that can be extracted from marine currents (by turbine generators) is dependent on the speed of the water flow, and the area and efficiency of the turbine, as follows:

$$\text{Power} = 0.5 * \rho * A * v^{3} * Cp$$

- ρ is the density of seawater (approximately 1025 kg/m³)
- A is the area swept by the rotors (m²)
- v is the current speed (m/s)
- C_p is the efficiency factor of the turbine.

The density of seawater means that marine turbines are significantly smaller
than wind turbines of similar generation capacity, and rotate at approximately 20 to 30 rates per minute.

The essential components like rotor, hub, gear, generator and tower come from the wind power technology. But, in contrast to the power production from wind force, water has a much higher density than air. The result is thousandfold as much as the power of airflow when there is a steady water flow, which is why the flow speeds (relatively slow in the water), as they originate possibly from the tides, are sufficient for the production of electricity.

The 2-blade rotor has a solid orientation along the direction of the flow and a pitch settlement which allows a blade adjustment of about 180 °. Therefore the operation is possible equally with low tide as well as with flood. Besides, the pitch settlement is used for the line limitation and retardation of the equipment. Rotor, gear and generator are fastened together in a framework and can be lifted out of the water with the help of a lift device to carry out the maintenance.

Another concept for the use of sea flows is the Stingray Tidal Stream generator. The Stingray uses, in contrast to tidal turbines, no air-screw but a compensator arm for the power production from the sea flow. To guarantee the stability at the bottom of the sea, a star base with four beams is applied, which are anchored in the ground. The compensator arm is fastened to a column on the star base. The construction weighs approx. 180 t and it is its simple dead weight which gives it a good anchorage at the bottom of the sea. By the undulation of the water the fin of the compensator arm oscillates up and down. That is how the pressure is generated inside a hydraulic cylinder which is used to power a generator.

In the years 2002 and 2003 the equipment was tested with an installed rating of 150 kW as a pilot scheme. After building a demonstration equipment in 2005, the enterprise Engineering Business Ltd had arrived at the conclusion that the equipment construction would possibly not be practicable in consideration of profitability.

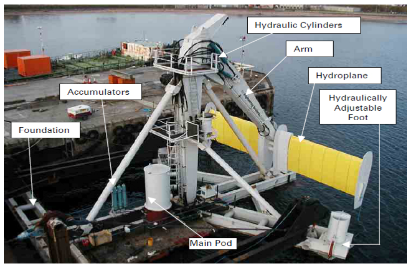

figure 4: Stingray Tidal Stream Generator

All in all, sea flow power stations could become reliable energy suppliers in the future above all due to the computability of the tides. They work silently and hardly disturb the landscape. Besides, a combination with offshore wind parks could create considerable synergy potentials, for example, by using a common grid connection. Only in Europe more than 100 suitable locations for such equipments would be possible at a guess. Nevertheless, it is problematic that suitable and unsuitable locations are often established close to each other. When a good location is being searched for, it is also important to consider the possible potential for conflicts with other ocean users sufficiently, apart from disputable environmental conditions. Before a commercial production of electricity can become reality, a huge number of detailed questions is still to be solved with regard to the equipment technology to guarantee a safe and frictionless operation under rough conditions, like the sea water.

Another alternative of producing electricity is using wave energy. At this, 3 possible technologies are available after all:

- *Oscillating Water Column:* the periodical, vertical movement of the water compresses and relaxes air with an airborne turbine.

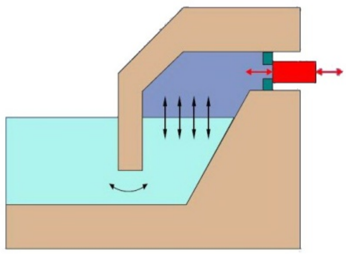
figure 5: Wavegen

- *Wave-induced Drop Height:* shafts lift the water on a higher energy level. The potential energy is taken up by a "low head" turbine.

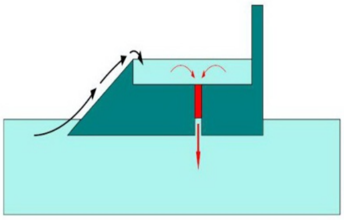

figure 6: Wavedragon

- *Hydrodynamic Movement:* buoyancy bodies follow the undulation. Out of this, the most different possibilities of direct energy conversion arise.

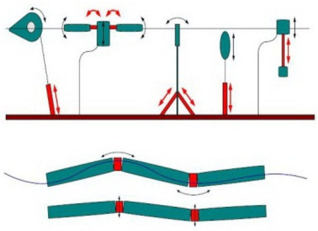

figure 7: Pelamis

figure 8: Pelamis- Wave-Generator

The Pelamis-wave power station is a 750-t-steel construction which generates electric current by moving the single limbs in opposite directions. This 150-m-long and 3.5-m-wide steel tube is divided into four cylinders which are connected by power modules. In the modules there are piston pumps which take up the kinetic energy and deliver it to a hydraulic generator by means of the hydraulic liquid. The capacity of the equipment constitutes 750 kW. An anchor holds the construction in the intended position and is flexibly applicable with it, in contrast to other sea power stations, and has a lower impact on the ecological balance. The first commercial employment occurs in 2008 in Portugal, being part of the pilot project of 2006. In this connection it concerns three equipments. For the future it is planned to start another 25 equipments running which will have a total capacity of 18.75 MW.

The Wavegen project is one of the most reliable sea power stations. The energy of the water is not used directly, but the working medium air is. The structure is partly on shore and in the water. It contains a hollow cavity which is flooded by the sea. With waves streaming in, the water level changes inside the structure. An alternately high and low air pressure inside arises from it. The pressure is compensated with the aid of an open end towards the environment. Close to the open end, there is a Wells turbine which dissipates the kinetic energy of the flowing air into electric energy. The Wells turbine distinguishes itself by the fact that it maintains its running direction while the air flow is varying, so that it supplies permanent electricity. Before a Wavegen project can be realised, comprehensive investigations about the characteristics of the waves have to be carried out.

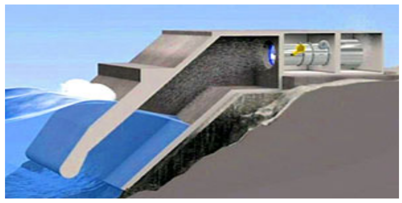

figure 9: Wavegen

An implementation of the equipment construction has been on the Scottish island of Islay since the year 2000.

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