Renewable energy from the oceans – Wave power, tidal power and ocean streams

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I. Introduction

When thinking about renewable energies, wind, solar and hydro energy typically come to mind.
To tackle climate change and all the challenges imposed by the need to find alternative and reliable energy sources, there is one major resource that has remained untapped until now: marine energy.

The potential of wave energy has been recognized for long, and mostly associated with a destructive nature. The following paper will give the reader a short overview about using wave and tidal energy as a renewable energy source.
Wave energy is a concentrated form of solar energy: the sun produces temperature differences across the globe, causing winds that blow over the ocean surface. These cause ripples, which grow into swells. Such waves can then travel thousands of miles with virtually no loss of energy.
The total wave energy resource is as large as world electricity consumption, approximately 2 TW. About 10-25 % of this resource is economically usable. [1]

Tidal power occurs because gravities of the moon and sun combined with the rotation of the earth cause periodic changes of the oceans. These changes are called tidal range. The considerable level difference between high tide and ebb at many coasts of the earth generates an enormous energetic potential, which can be opened and used by the mankind.
Furthermore, it is possible to use the energy of ocean streams which are caused by the complex interactions between warm and cold layers of water.
The global theoretic potential of tidal energy is approximated at 3000 GW, but about 100 GW are realistically recoverable. [2], [3]

II. Utilization of the tidal range - Tidal power plants

Tidal power is the result of the gravitational interaction between the moon and the earth. This gravitational force, combined with the rotation of the earth, produces a twice-daily rise and fall of the sea level, called ebb and flood.
The period of one tide is for example 12.4 hours at the France coast. The difference in water levels is used to convert the potential energy into kinetic energy, by passing through the turbines. [4], [5]

Tidal power is predictable and reliable, but it can be used economically first at a tidal range of 3-5 meters.
At a tidal power plant the water fills during the high tide a basin that is separated from the sea by a barrage.
During the following low tide the accumulated water is used to drive the turbines of the power station. The turbines can work also in the time of the filling process. Tidal barrages are built across a suitable estuary or bay. [6]

There are several operational modes: ebb and flood generation and a two-way-generation.
At the flood generation (see at Fig. 1) the sea level is higher than the basin level, so the water passes the barrage and fills the basin. The barrage then is closed to dam and to create a hydrostatic head. At the ebb generation (see at Fig. 2) the water will pass the barrage from the basin to the sea when the sea level has fallen under the basin level.
A single basin system can deliver electrical energy only half a day. An option is the double-basin system. One basin will operate in flood generation and the other in ebb generation. Both basins are connected and it is possible to use this construction as pump storage power plant. The main basin will be filled at the high tide and pumped the water to the second basin. During the ebb, the second basin will generate the electricity. [4], [5], [7]

There are different types of turbines that are available for use in a tidal barrage: bulb, rim and tubular turbines.
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.
When rim turbines are used, the generator is mounted radially around the rim and only the runner is in the flow. This turbine is more efficient because the water flow is not so constricted.
The tubular configuration sets the runner at an angle so that a long tubular shaft can take rotational power out to an external generator. [6]

The idea of tidal power plants is known since the end of the 19^{th} century. In 1913 the first tidal power plant was built in Husum / Germany. At present there are only a few tidal power plants in operation. The largest power plant is situated at the river Rance / France near St. Malo with a maximum power of 240 MW. [5], [7]

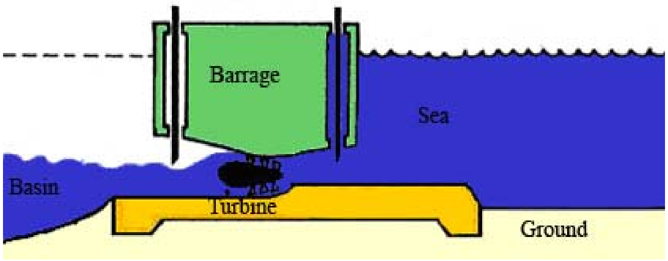

Figure 1: flood generation with a bulb turbine
Source: www.seas.upenn.edu; date: 25 February 2009

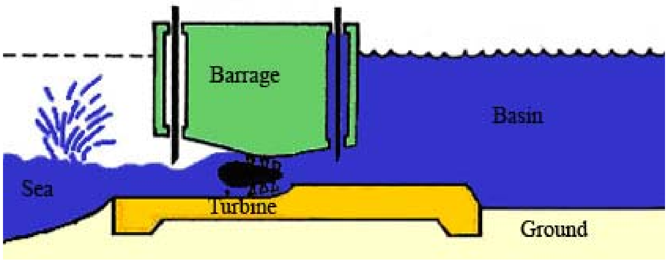

Figure 2: Ebb generating system with a bulb turbine
Source: www.seas.upenn.edu; date: 25 February 2009

III. UTILIZATION OF NATURAL ENERGY FLOWS – OCEAN CURRENT POWER PLANTS

An Ocean Current Power Plant (OCPP) works similar to the functionality of wind turbines. Both types of power plants make use of the kinetic energy of the streaming medium, which they are surrounded by.

Advantageously for sea turbines a lower flow speed is needed [8]. Compared to the air current it is much easier to predict marine current due to less important random effects. The streaming is whether driven by the tides or by oceanic circulations. Therefore prognoses for generated electricity are more reliable as well [9].

The submarine turbines are anchored at the bottom of the ocean and the outlet of electricity happens via undersea cable.

To achieve an ideal economic usage, the water depth must be 20 – 35 meters and the flow velocity must reach 1.5 – 2.5 meters per second [10]. Due to the water density, which is a thousand times higher than air, ocean current has a much higher power density. Compared to the face of wind turbine, submarine rotors realize a performance that is eight times higher. The prototype of „Seaflow", an OCPP, reaches a performance of 350 kW at 20 cycles per minute. Prototypes using a twin rotor already reach a performance of 2.1 MW (see Figure 3, right) [10].

The impact of saline environment is problematical due to the process of decomposition that affects on the construction materials of the machines. The construction of OCPPs has effects on the speed of the ocean current and with this on maritime ecological system as well. The locations of OCPPs influence the barge traffic by getting into the ships routes [8].

In Europe approximately 100 locations exist, where OCPPs are going to be built. The whole potential is estimated on 70 TWh per year. Thereby 2-3% of the European current drain could be satisfied [10].

Figure 3
left: prototype "Seaflow" at the west coast of Britain (photo: ISET)
right: planed OCPP (graphic: *Marine Current Turbines*)
Source: Quaschning, V. (2007): Regenerative Energiesysteme – Technologie, Berechnung, Simulation, 5. Auflage, München: Hanser-Verlag 2007

IV. UTILIZATION OF THE CONTINUOUS UNDULATION - WAVE POWER PLANTS

A wave carries both kinetic and potential energy. The total energy of a wave depends roughly on two factors: its height (H) and its period (T). The power carried by the wave is proportional to H^2 and to T, and is usually given in Watt per meter of incident wave front. The energy content of a wave is determinable by application of the linear wave theory. [11] The total area of the seas amounts to 360.8 million km². If half of the body of water is raised only around 0.5 m, then 0.6 EJ are stored in the form of potential energy. [12] To use the wave energy however only areas of offshore regions with low water depths are possible. Thus less than 1% of the demand of electricity could be covered by German waters. [12] The energy of the sea waves can be used differently for power production. Attention should be paid to the capacities of a wave which are not always constant. That means an energy converter is needed that works with a high efficiency at all ranges of performance. In addition with to the construction of the plant you have to consider the largest wave which can be expected to accident avoidance. Furthermore the used material must be adapted on the rough maritime climate and the aggressiveness of sea water. [11]

At this point of time three considerable operational principles for wave power stations are developed:

- OWC system (oscillating water column)
- Floating system (Pelamis technology)
- TapChan

A. Oscillating water column

With OWC systems a chamber with air inclusion is created. A wave enters from the bottom in the closed chamber.
The air of the chamber is compressed and drives a turbine and a generator. With the reverse flow of the wave, air flows again through the turbine back into the chamber. [11], [12] For OWC a Wells turbine is used which rotates in the same direction regardless of the air flow, thus generating irrespective of up-ward or downward movement of the water column. [3] The capacity range of these plants extends over 500 kW up to several MW capacities. [11]

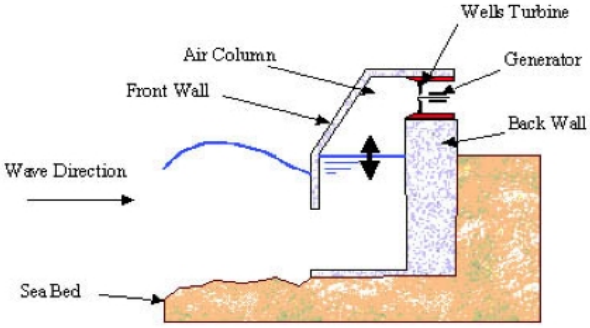

Figure 4: Schematic of an Oscillating water column,
Source: www.montaraventures.com/pix/oscillating-water-column.jpg
date: 25 February 2009

B. Floating System

Floating systems use the potential energy of a wave. These systems consist of a tubular with an air filled lifting body. At the hinged joints from the lifting body, hydraulic pistons are fixed. Due to the undulation the hydraulic pistons are pressing an operating liquid under high pressure into a compensating reservoir. Thus a hydraulic generator is powered [11], [12]. The stationary part of the plant is deep-seated at the sea bed [13]. The capacity of a generator amounts to approx. 750 KW. By linkage of several generators a total output about 30 MW could be obtained [12].

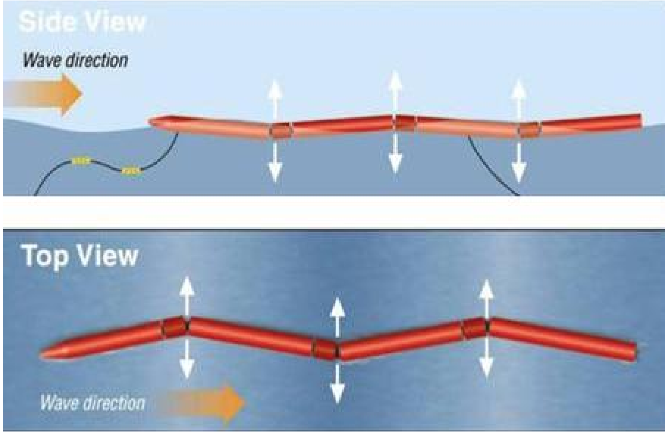

Figure 5: Floating system
Source: www.enel.it/azienda_en/ricerca_sviluppo/dossier_rs/img/Pelamis.JPG,
date: 23 March 2009

C. Tap Chan

Tap Chan is an abbreviation for "Tapered Channel". The waves in coastal area taper to an artificial ramp. The water which has a higher potential energy is collected in an upper reservoir. The artificial head is used to operate turbines, for example Kaplan turbines. [11] A huge disadvantage of this installation type is the high place requirement in the coastal area [12].
If "Sea-parks" were build with a lot of such plants then approx. 30% of European power requirement could be covered with wave energy [11].

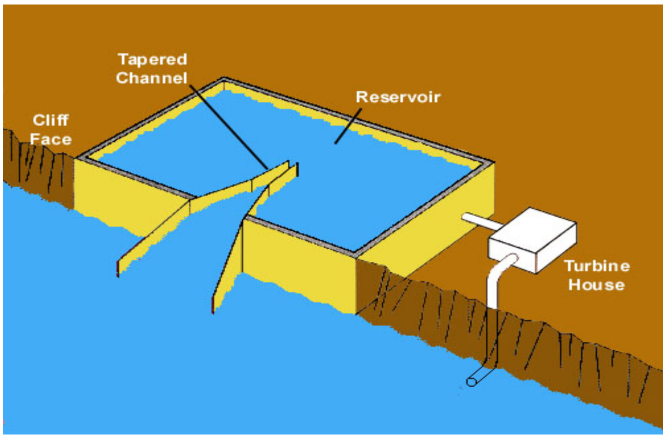

Figure 6: Schematic of a Tapered Channel
Source: http://www.rise.org.au/info/Tech/wave/image007.jpg,
date: 25 February 2009

V. OUTLOOK

Presently there are only a few power plants that are operated commercial, the others are for research. Therefore it is difficult to say how much it will cost, for example the investment for each kW.

There is still a lot to be done. As already mentioned the potential for renewable energy from the oceans is still there.
Altogether, although tidal energy is a reliable source, however the technically usable potential of the tidal energy appears globally seen too low, that it could make a substantial contribution for power supply of the future.
For Germany it is not possible to use tidal energy because of technical reasons. At German coastlines the tidal ranges amount to just under 3 meters.

The basic problems in using wave power are trivial and generally known: Wave power is unstably and could not affect in its size. Large waves have also a destructive nature.
The problem solutions, in order to arrange an economical usage of wave energy with justifiable impact on the environ-ment, are however not trivial.
It is very complex and expensive to build a power plant which resists the large waves.
Researchers believe that only large power plants with a high efficiency are competitive.

As well as the potential of wave power is relative low in Germany because the waves and streams at the coastlines and estuaries are too small for an economical usage.

Finally, against the background of more scarcely becoming resources of fossil fuels much efforts will be made to use the actual potentials in order that energy from the oceans make a contribution, whatever to which amount, to the world´s energy mix. [14], [15]

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