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Energy retrieval from sea currents and tides

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Abstract

Seas and oceans show variations in water levels caused by tides and continuous flow of water in the form of sea and ocean currents. Tides are most visible close to the coastline – tide parameters (water speed or change in sea level) allow construction of installations producing electric energy. Sea currents – superficial and deep are characterized by means of constant speeds and directions. Therefore energy retrieval from these elements of sea environment looks very promising. The article presents basic information on tides and currents useful for designing hydroelectric power plants. The already constructed hydroelectric power stations are also presented here together with several design solutions of future such installations.

Introduction

Two basic elements of sea environment: air and water are in constant motion throughout a major part of the year. Air travels over the sea surface in the form of wind, and water in the form of sea currents and tides as well as waves (however the movement of water particles is here totally different than in sea currents or wind). The area covered by seas and oceans constitutes approx. 71% [1] of the surface of the Earth, it is therefore easily conceivable, that energy resources of wind, sea currents and waves are truly immense. However, there is mainly a technical problem of obtaining such energy, as well as the effectiveness and productivity of this process.

Research into retrieving at least part of energy from sea environment has been carried out for a number of years. One of the most effective sources of renewable energy are sea tides and currents. The paper presents some (chosen) hydro installations and their efficiency.

Tides

Tides characteristic

Tides are the largest and most regular periodic movement of ocean waters, which can be described as periodic rise and fall in sea level. This phenomenon is caused by attraction forces of the Sun and the Moon and also the inertia forces in the Earth-Moon-Sun system. Tidal-related changes in the water level are imperceptible in the open ocean, however they can be easily seen close to the shore [2].

There are two elements which can be distinguished in tidal phenomena: a vertical movement of water masses and a horizontal movement, called a tidal current. As a result of a periodic tide-generating force action, a very long regular wave emerges on seas and oceans. It's period results from the exciting force period. Water particles of a tidal wave travel along elliptical, very much flattened orbits in the horizontal plane. Due to a very long period of a tidal wave the speed of a tidal current and changes of the water level can be separately determined, although both of them are interrelated.

Tide observations across the globe show, that high and low tides behave differently in various regions. They can therefore be divided into:

1. Diurnal-tides – occur when there is one high tide and one low tide during the day. Such tide is also referred to as tropical tide [2].
2. Semi-diurnal tides – emerge when there two tidal waves during one lunar day, which means

that the tide period lasts 12 hours and 25 minutes. In such tide both high tides reach the same height, and at both ebb tides water falls to the similar levels [3].

3. Mixed tides – these are tides of different levels of low and high tidal waters, also with different time of high and low tide times during moon day. They emerge as a result of day and half-day tidal waves [3].

Tides can also be divided according to the position of the Earth in relations to the Moon and the Sun. Syzygian current occurs when the Earth-Moon-Sun form a straight line. Then tidal-forming forces of both the Moon and the Sun, sum up and the tide reaches its maximum, which means that the difference between the peak high and low tide is the largest [2]. This phenomenon can be observed twice a synodical month: at the time of highest Moon (full Moon – the Earth is between the Moon and the Sun) and when the Moon reaches its lowest point (new Moon – when the Moon is between the Earth and the Sun). When the Moon reaches the point, that (theoretical) lines joining the Moon and the Earth and the Sun and the Earth form the right angle, then the resulting tide is quadratorial (minimal).

Tide parameters

High and low tides are measured across the whole world. Maximum difference values in sea levels and tide periods on various open sea and coastal areas are given in special sea maps. An example of such map with maximum values of vertical water movement of syzygian tides is shown in figure 1.

An example of graph showing changes in water speed at high and low tide at a given sea area is given in figure 2.

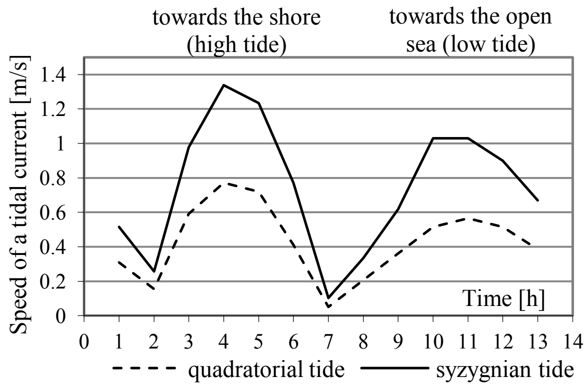

Fig. 2. Change in speed of a tidal current dependent on time

Characteristic values of tide parameters are as follows:

- average velocity (up to 2.0 m/s),
- average direction,
- vertical tidal water movement
- (up to 10 m; max. 18 m).

} periodically changeable deterministic parameters (period – diurnal or semi-diurnal)

Sea currents

Sea currents characteristics

A sea current is a turbulent movement of water masses in seas and oceans, which can be characterized by a determined speed and direction. Due to very slow changes in both speed and direction in time, a sea current is treated as a determined phenomenon of quasistatic mean speed V_C and direction γ_C.

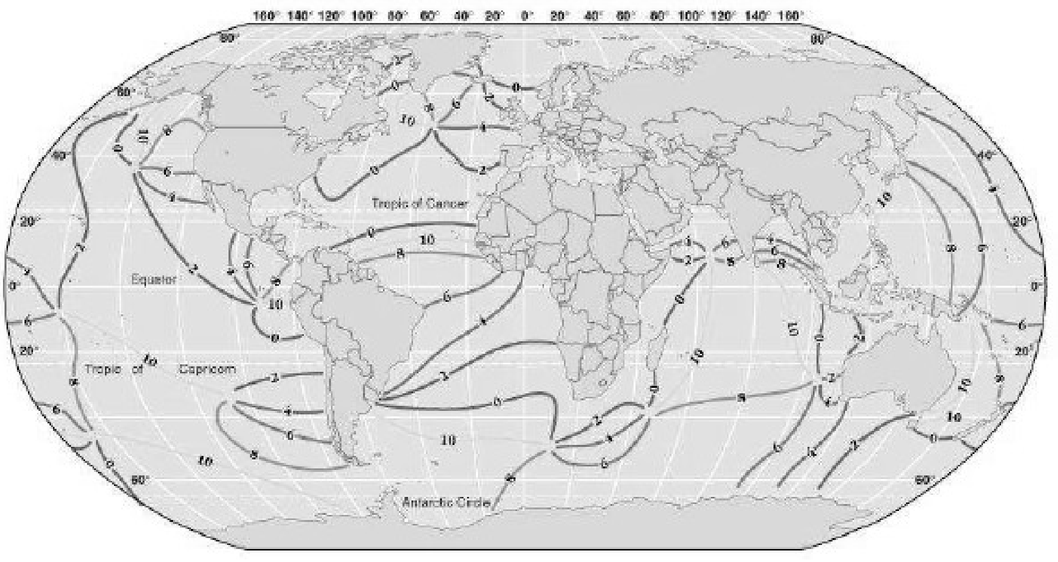

Fig. 1. Map of maximum values high of syzygian tides [1]

Sea currents can be divided according to:

- their original cause – tidal, wind, drift, gradient;
- the depth at which they occur – surface, subsuface, undercurrent, and those closest to the seabed;
- directions – vertical and horizontal;
- duration – constant and temporary;
- thermal characteristics, in relation to surrounding waters – warm and cold.

With the view of an overall goal set for this paper, only superficial sea currents occurring on selected sea routes will be taken into account, irrespectively of the original cause giving rise to such current.

Tidal currents – horizontal movement of water caused by tides (tides result from the interaction between the Earth, the Moon and the Sun). In the open oceans they are imperceptible (average speeds are too small to be accounted for and can be ignored).

Wind generated sea currents – result from a friction of air against the water surface during a short wind action. Such winds disappear shortly after the wind has stopped blowing. Wind generated currents occur in the surfaces of water, and their direction is concurrent with the predominant wind direction. Average speed of such current due to a short-lasting wind action is very small, and therefore will not be taken into account further.

Drift currents occur as a result of a long-lasting and constant – in terms of direction – wind action on the surface of the sea. Comparing to the wind-related currents, they reach deeper and affect larger masses of water. The Coriolis force, water mass inertia and friction cause that the two main parameters of drift currents: direction and speed change together with depth (Fig. 3).

On the northern hemisphere, the drift current deflects from the wind direction to the right, while on the southern – to the left. At the superficial level, such deflection stops when the Coriolis force is counterbalanced by the component of a friction force perpendicular to the wind speed vector, namely, at approx. 45° deflection.

The speed of a superficial current, generated by a long-lasting wind action in the open ocean amounts to approx. ca. 0.01÷0.02 of wind speed, measured at 10 m above the sea level. Drift currents in the open ocean can reach the speed of approx. 0.5 m/s.

Gradient currents (density related) result from differences in water density between superficial and bottom levels of water. While lighter water masses move upwards, the heavier (more dense) move down toward the sea bottom and vertical currents emerge. Changes in density are predominantly caused by temperature changes, and more rarely – salinity variation.

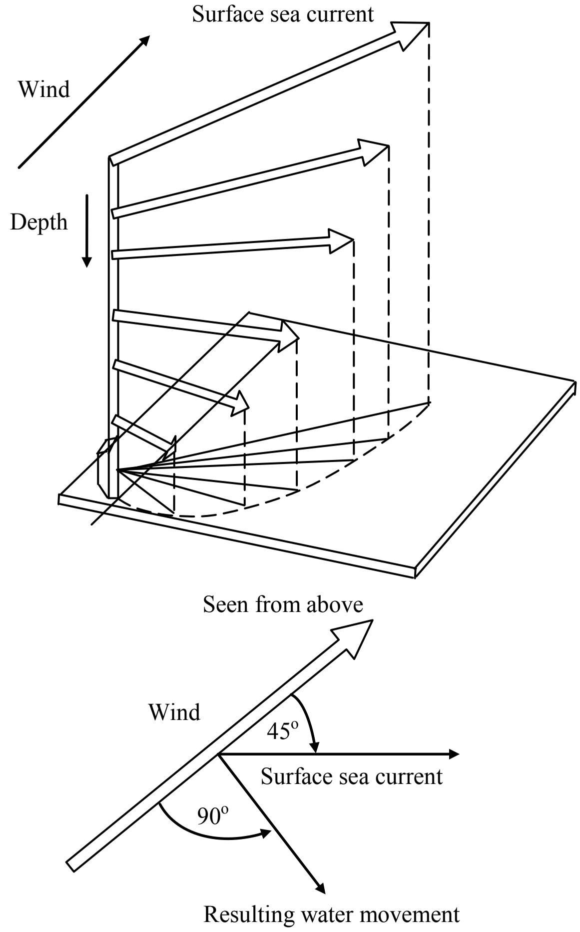

Fig. 3. The influence of sea depth on the direction and speed of a drift current (The Ekman Spiral)

Large-scale superficial currents

The currents so far discussed, have a defined place of occurrence as well as duration depending on the original factor giving rise to each of them.

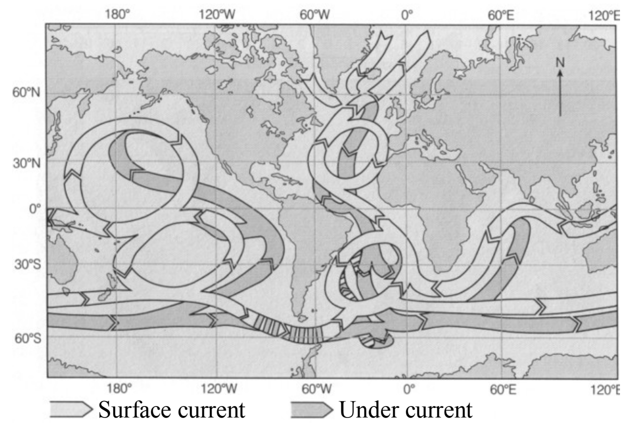

Fig. 4. Large-scale surface and ocean under currents [1]

There are, however, also large-scale superficial and deep currents which move in determined directions at determined speeds and depths in a continuous way. The movement of ocean waters in such currents is of a closed circulation in nature, and they result from trade winds. Due to closed circulation, such currents moving surface collect warm waters, and come back carrying cold water (either in the form of surface or under currents) – Fig. 4.

Currents parameters

Characteristic values of superficial currents parameters are as follows:

- average velocity (up to 2.5 m/s); } deterministic parameters
- average direction; } deterministic parameters
- depth at which they occur – superficial and deep of closed circulation.

Power stations and technical devices for retrieving energy from sea currents and tides

Tidal energy retrieval

Tidal hydroelectric power plant. A hydroelectric power plant is the most popular technical solution using tidal energy to generate electric current: it is basically a dam across a canal (bay) with Kaplan turbines within it (Fig. 5 and 6).

In hydroelectric power station of such type, energy can be retrieved from a single (e.g. only during high tide, Fig. 7) or double cycle (both high and low tides, Fig. 8).

In order to use a double cycle of energy production (during high and low tides) – reversible water turbines have to be installed in a dam. In a double cycle there can also be periods, when a turbine has to work as a pump for some time (using part of the generated energy), however the total sum of energy produced is still higher than in the case of a single cycle.

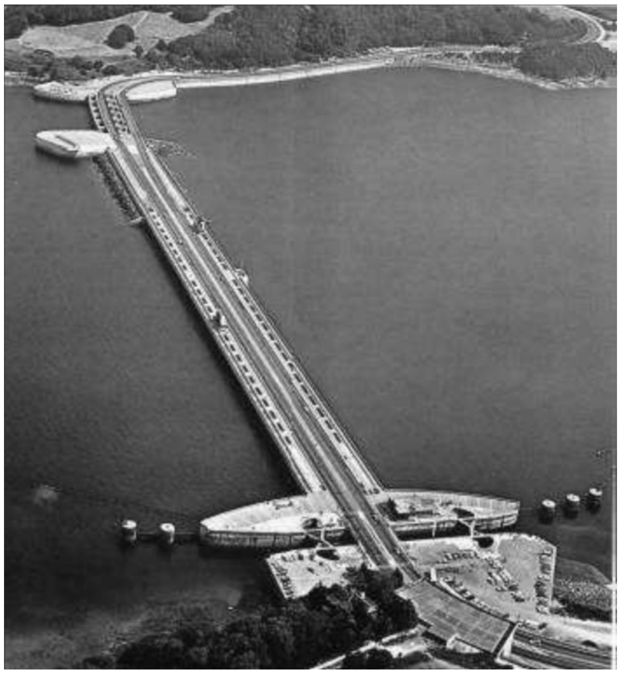

Fig. 5. Tidal power station in France [4]

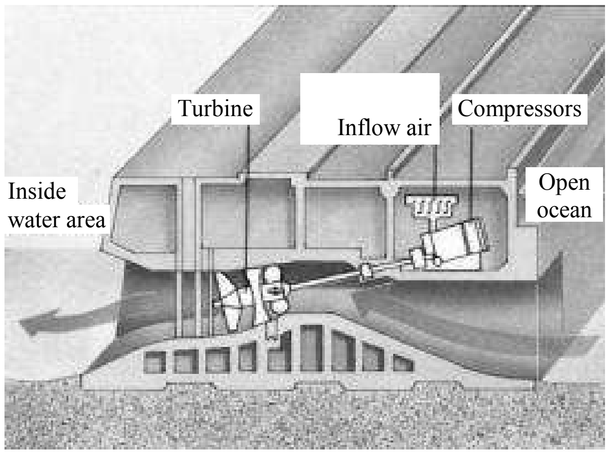

Fig. 6. Dam joining the mouth of the river and water turbine [4]

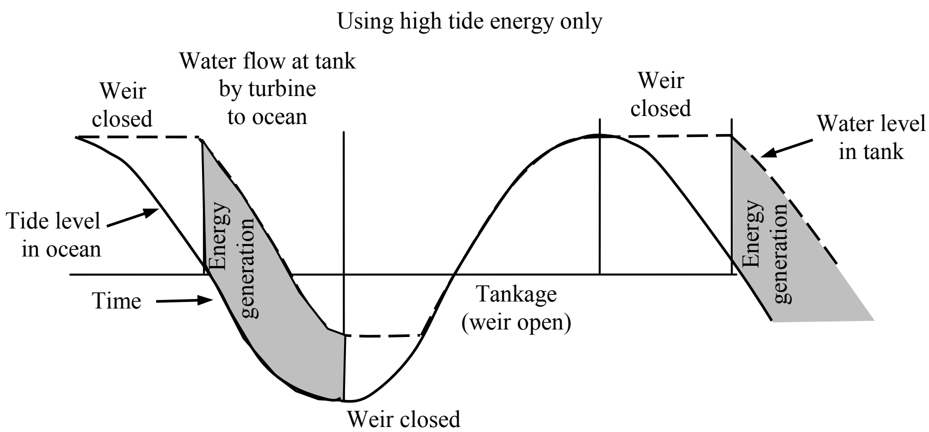

Fig. 7. A single cycle of generating electric energy in a tidal hydroelectric power station [4]

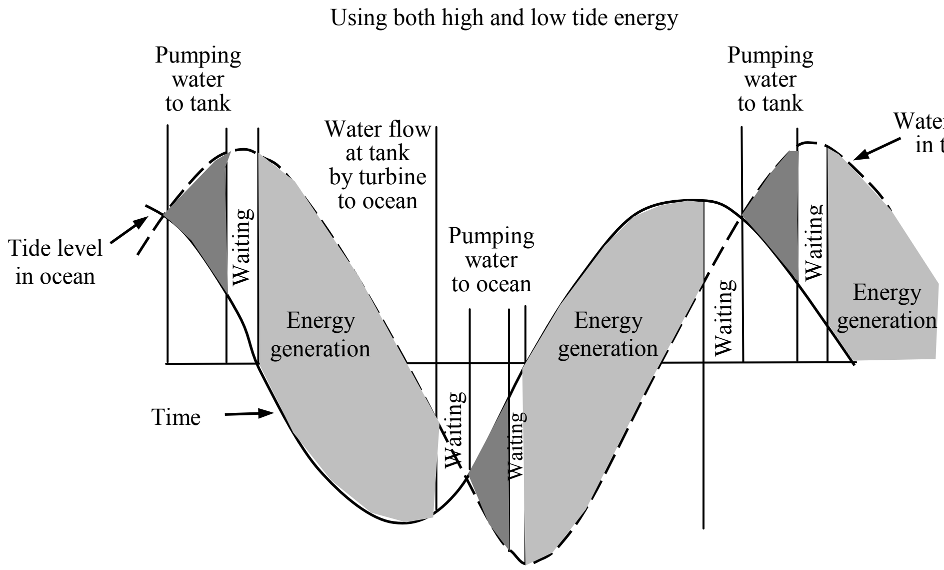

Fig. 8. A double cycle of generating electric energy in a tidal hydroelectric power station [4]

Fig. 9. Hydroelectric power station "Seaflow" in Dovon [5]

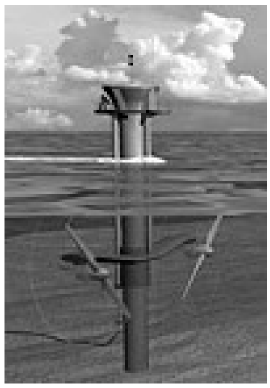

Fig. 10. SesGen hydroelectric power station – a design [5]

Fig. 11. " Sabella" at the mouth of the Odet river in Bretany [6]

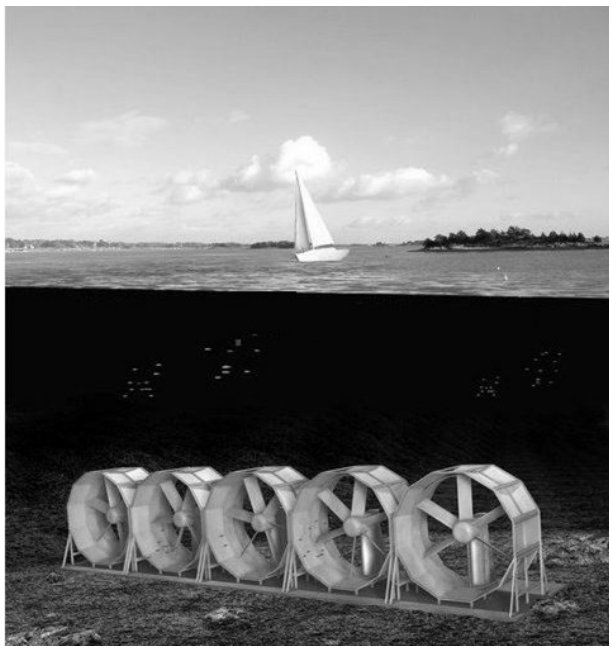

Fig. 12. "Sabella" hydroelectric power station – a design of HydroHelix company [6]

Subwater turbines

Where it is not possible to build a dam or sea is too deep, Kaplan's turbines with (electric current) generator can be installed. Such hydrogenerators are similar in function to wind turbines. They can be mounted on supporting columns seating on seabed (Fig. 9 and 10) or seated directly on seabed (Fig. 11 and 12).

Energy retrieval from sea currents

Energy from sea currents can be retrieved in a similar way and using similar devices as from the tides. Subwater turbines can be:

- located in a subwater dam;
- free standing (freely located) – when the speed of the current is sufficient, or when dam construction is unprofitable.

In case of sea currents, due to a constant mean value of sea current speed as well as its direction in the long run, turbines are simpler and generated energy is also characterized by a constant mean value over a long time.

Conclusions

- The power of a tidal hydroelectric power station changes with speed changes in tide, and also in tide direction. In an electric power station such power is constant.
- Tidal hydroelectric power stations are usually installed shore (in a bay, at the mouth of a river).
- Electric power stations, due to the required speed of a sea current, can be installed in fewer places close to the land.New designs of electric power stations are mostly located in sea areas further offshore (with sea depth increasing there are also more problems with mooring – anchoring of such turbines).
- There are no limits as to the size of sea current turbines and their rotational speeds, and hence energy retrieved (turbine power).Effectiveness of water turbines (tidal or sea current) can be higher than in the case of wind turbines, however the investment costs are still very high.
- Water turbines, due to water density (over 800 times higher than that of air) reach the same power as the wind turbines at far smaller dimensions and speeds even 100 times smaller than the wind speed.

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