Current systems and potential areas for tidal power plants - A review

Using the example of the United Kingdom

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Abstract

This review is about where and which tidal power systems are currently deployed. It starts with an insight into the variety of different tidal power systems. With the help of a list from the European Marine Energy Center about currently used systems for tidal power plants, it quickly becomes apparent that two systems stand out. These are the vertical and horizontal turbines. The latter are particularly common, as they are used for both tidal stream and tidal range power plants. Determining the regions with high potential for tidal power is not always easy due to the many influencing factors. Influencing factors are, for example form and conditions of the seabed, topographical features of the coast or currents in the sea [1]. Therefore, each region must be considered separately. n this paper the focus is on the UK, the literature shows that the coastal regions around the UK provide about 50 TWh/year of the European tidal power potential. This is due to the location between the oceans and the geological conditions, which act as a channel for the tides. The two areas with high potential where planning and construction of tidal power plants is currently underway are in the north of Scotland and in the southwest of England in the Bristol Channel.

Keywords: renewable energy, tidal range, tidal current, ocean energy, potential areas

1 Introduction

The importance of renewable energies is increasing, especially in recent years and months. So far, wind power and photovoltaic plants are very often erected, which generate electricity from renewable sources. With these two methods, electricity generation is difficult to predict and is highly volatile [2]. Until now, fossil fuels in the power industry have compensated for the planning difficulties and volatility of renewable energy. However, the use of fossil fuels is to be reduced to an absolute minimum in the future. There are various ways to compensate the planning uncertainty and volatility of wind and photovoltaic plants. Examples are electricity storage or the production of hydrogen. These two methods can be used in case of overproduction of electricity, which mainly absorbs the volatility and increases the planning reliability to a certain extent. Another method is the production of electricity from tidal power. Tidal power has very high predictability and low volatility in electricity generation [3]. Therefore, a large portion of the base load in the power grid can be covered by tidal power. This paper first gives a general insight into the different tidal power systems, from which the two application types tidal current and tidal range emerge as the currently most effective and widespread methods. This is followed by an insight into the potential of tidal power in the world. The UK has about 48 % of the potential for tidal power in Europe, with an estimated 50 TWh/y [4]. The focus of this paper is therefore on the region around the UK. At the end, the insights gained are brought together while practical examples of tidal stream and tidal power plants are briefly presented.

2 System variants categorize and emergence of tides

2.1 Appearance of the tides

In any large sea, the water level regularly rises and falls. This phenomenon is called tides. This course is divided into two processes low tide and high tide. The latter describes the process of rising water level. No seashore is free of ebb and flow, but the manifestations of the two processes are sometimes very weak and not noticeable.[5]

The cause of high and low tide lies in the interaction of the gravitational pull of the Earth and the Moon. The water on the Earth is attracted by the Moon, and some of the water flows towards the Moon. Due to the rotation of the two masses in relation to each

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other, additional centrifugal forces occur, which ensure that water also flows towards the opposite sphere of the Earth. This increases the water level at two opposite points on the globe. The sun also has an effect on the tides with its gravitational pull, but the sun's influence is much less than that of the moon.[5]
The influence becomes particularly clear after full and new moon, since the tidal range can assume highest values. The centrifugal forces are in equilibrium, but they are not equally strong at all points on the earth's surface, two elevated water heights opposite each other on the earth's sphere are formed due to the centrifugal force. Due to the rotation of the earth and the standing water elevations, low tide and high tide arise. [5]

2.2 Overview of tidal power plants

At the beginning, the difference between tidal stream and tidal range power plants is pointed out. In addition, there are turbine systems and non-turbine systems. A list of common examples of the two types of systems is presented in Tab. 1. With this table, the variety of different applications of tidal energy can be seen. In case of tidal current, the energy is usually drawn from the moving fluid via rotor blades. As with wind turbines, the turbines in tidal stream power plants have rotor blades with an airfoil cross-section which operate according to the principle of aerodynamic lift [6]. Tidal range power plants use the height difference between high and low tide to generate energy. The water is dammed up in a basin before it is released over turbines [7].
The following list by M.J. Khan [3] shows interconnected concepts for the use of tidal power. These concepts are divided into two classes (turbines/non-turbines). This list gives an impression of the different possibilities to use tidal power. For a more detailed explanation see M.J. Khan [3].

Tab. 1: Possible systems for the use of tidal power [3]

Turbine Systems	Non-Turbine-Systems
Axial (Horizontal)	Flutter Vane
Vertical	Piezoelectric
Cross-flow	Vortex induced vibration
Venturi	Oscillating hydrofoil
Gravitational vortex	Sails (Tidal Kite)

We cannot consider all types of tidal power plants in this paper. For this reason, the focus is placed on the systems that are most frequently encountered in practice. To identify these systems, a list of the European Marine Energy Center (EMEC) [8] is used. EMEC is a facility where different tidal projects are listed with project specific data, giving an overview of the systems currently in use. An overview of the tidal power plants considered in more detail in this paper is developed in Section 3.1.

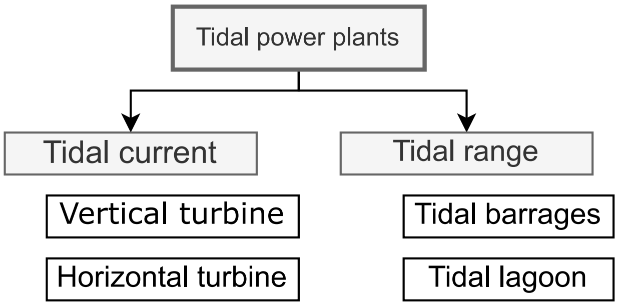

Fig. 1: Overview of the considered tidal power systems in this review, own image

3 Superior tidal power systems and potential areas

3.1 Considered tidal power plant systems

As mentioned, the list of tidal power plants under consideration is now being developed. For further consideration it is important that the systems have left the status „proof-of-concept"and are used in first full scale projects. The list from EMEC includes 97 systems from real projects, and there are two systems that are particularly common. These are the systems with a horizontal turbine (43 out of 97) and the systems with a vertical turbine (16 out of 97) [8]. These two turbine systems are used especially for tidal currents. In the case of tidal range power plants, horizontal turbines are often installed in the dams [7]. Figure 1 illustrates the systems considered in more detail in this paper. It is pointed out that this figure is not complete. Likewise, if the criteria remain the same, the content may change in the future.
A short explanation of each system is given, for more detailed explanations, the following sources are recommended [3, 7].
Tidal current:

- Vertical turbine: The axis of rotation of the rotor is perpendicular to the water surface and also orthogonal to the incoming water stream. Lift or drag rotor blades are used [9].
- Horizontal turbine: Rotating axis is parallel to the incoming water stream. Also employing lift or drag type blades [3].

Tidal range:

- Tidal barrages: These are structures built around bays or estuaries. With the surrounding

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land a basin is formed, in which water can be dammed up [7].

- Tidal lagoon: A tidal lagoon consists of completely man-made basins in whose walls the turbines are built [7].

In the Fig. 2, the two turbine systems, vertical and horizontal, are illustrated schematically. The basic difference lies in the flow of water through the turbine respectively the orientation of the rotational axis of the rotors.
The generator of the vertical turbine is usually above the water surface and the turbine is connected to a floating body or to the shore [7]. In the horizontal turbine, all components are often below the water surface. There are also designs where the generator is above the water surface and the rotors are placed horizontally below the water surface [3].
Similar to wind power, only a certain amount of kinetic energy can be extracted from a moving fluid [6]. In order to exploit the potential of tidal power, large series of tidal turbines have to be erected in many cases. For a large tidal power plant, it is important to know and evaluate the existing tidal current in advance [10]. Areas with high potential for tidal power plants are discussed in more detail in the following section.
Each tidal power plant has its own tidal currents, which means that the design and construction of the turbines must be adapted. As a result, the manufacturing costs for tidal power plants increase, which is why a high yield is important for the economic operation of a plant [10]. For this reason, areas with a naturally high potential for tidal power are currently being selected for the construction of power plants. The next section presents areas with high potential for tidal power.

3.2 Areas with potential for tidal power

It is difficult to determine the tidal current velocities at different locations in the world using a general approach. The reason for this is the strong dependence of the current velocity on the local topography. Constrictions of a tidal channel or of a headland are usually strong influencing factors for high current velocities.[11]
However, there are basic principles on which the highest current velocities are based. As explained earlier, tidal waves are a reaction of the gravitational balance between the earth and the moon. At the University of Hull, Jack Hardisty and his team have conducted an analysis of the tidal current force. Eight regions with potentially high tidal currents were identified [11]. These eight regions are listed in Tab. 2.

In the region in northwest Europe, the areas in northwest France and around the United Kingdom (UK) in particular provide a great potential [11]. In this paper we will focus on the area around the UK.

Tab. 2: Regions with potentially high tidal currents [11]

Potential Regions for Tidal power in the World
North America and Canada
Barents Sea
South America
East Africa
West India
Australia
China Sea and Japan
North-West-Europe

The ABP Marine Environment Research Ltd. has identified 12 areas around the UK with high potential for tidal stream power [1]. These areas are listed in Tab 3.

Tab. 3: High potential areas for Tidal stream around UK [1]

Potential areas for tidal power around the UK	
A	Orkney Islands
B	Pentland Firth
C	Humber
D	Norfolk
E	Dover
F	Isle of Wight
G	Portland
H	Channel Islands
I	Severn Estuary
J	Anglesey
K	Isle of Man
L	North Channel

The Fig. 3 illustrates the areas with high potential for tidal power around UK mentioned in Table 3. Studies were carried out by Hardisty et all [11] for tidal power plants on the British coast. For shallow water tidal range power, two sites were identified:

- Pembrokeshire (1.4 km^2 and 110 MW)
- Bristol Channel (10 km^2 and 800 MW)

Similarly, three deepwater sites were identified:

- Angelesey (176 km^2 and 14 080 MW)
- Pembrokeshire (0.6 km^2 and 40 MW)
- Bristol Channel (8 km^2 and 640 MW)

4 Conclusion

Now we combine the findings from the previous sections. From the Table 3 and Figure 3, respectively,

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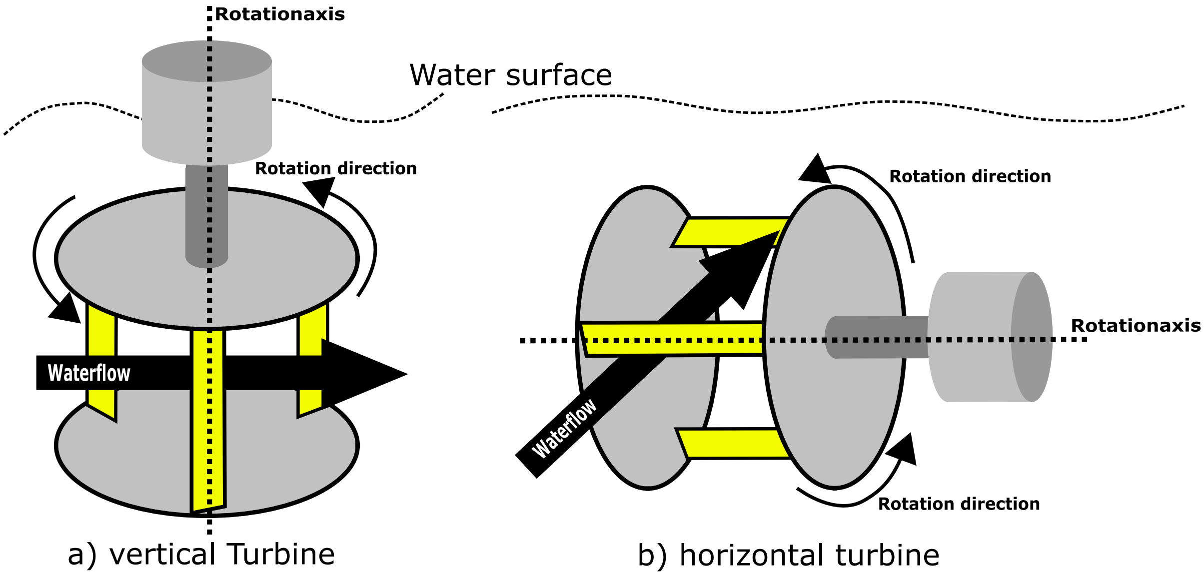

Fig. 2: Schematic drawing of vertical and horizontal turbine, inspired by [3, 7]

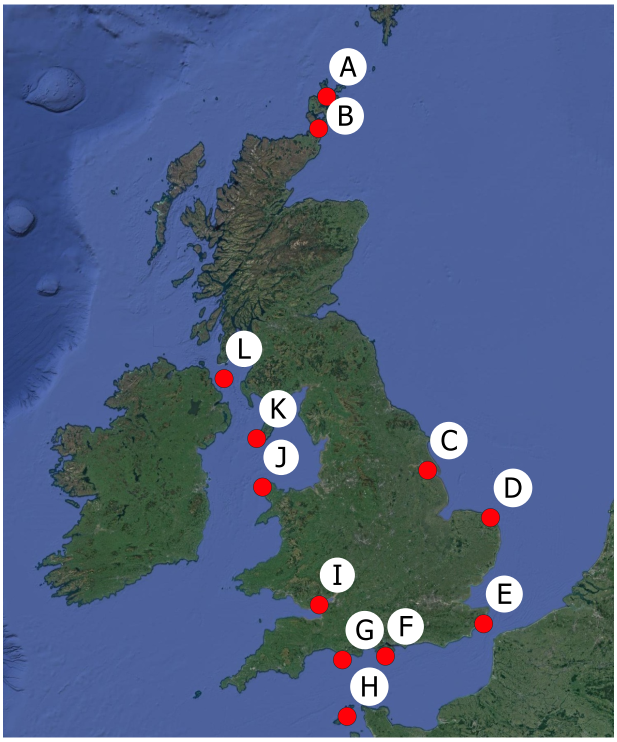

Fig. 3: Map of areas with high potential for tidal power plants around UK

it can be seen that the areas with high potential for tidal currents are distributed quite evenly, especially in the south (English Channel), and west of UK. Two potential areas are located in the north of Scotland. The coasts to the south and west act as a channel that increases the tidal current velocity [11]. The same applies to the Orkney Islands area in the north of Scotland. These naturally occurring channels make these areas particularly suitable. In the English Channel, however, the installation of a tidal power plant would be more difficult because there is a lot of shipping traffic.

With this knowledge and the findings of the EMEC [8] list, it can be said that it is appropriate to install the first tidal power plants in the west of the UK and in a smaller area in the north of Scotland. The high potential of the tidal stream makes it easier to establish economic viability. At the same time, experience can be gained for the technology of tidal power plants and thus a cost reduction of the technology can be expected.

The same applies to tidal range power plants. Here, especially bays that can be used as a natural dam to keep the construction cost low. The Bristol Channel is often mentioned as a bay with high potential for a tidal range power plant. [7, 11, 12]. There are also opportunities along the Scottish east coast for tidal range power generation with significant 24-hour power output [4].

5 Practice examples and Outlook

Tidal power has gained more attention in recent years. Accordingly, the technical systems have been further developed and are increasingly being operated economically on an industrial scale. Large tidal power plants are needed to make the most efficient use of the high potential worldwide. However, smaller plants also contribute to gaining experience for the technology of tidal power plants and thus to reducing the construction costs. For the most profitable operation, regions with high potential are preferred. Around the UK, these are particularly the areas in the north of Scotland and in the east and west of England, where the largest bays are located. There is also high po-

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tential in the English Channel, but here it would be more difficult to build a tidal power plant because there is a lot of shipping traffic. In general, it can be said that high potentials for tidal power can be found where coasts serve as channels and thus increase the potential for tidal power. In order to extract the kinetic energy from the moving fluid, mainly vertical and horizontal turbines are currently used, similar to wind turbines.

Two practical examples of tidal power plants in the UK are presented. One is a tidal stream power plant in the north of Scotland and the other is a tidal range power plant in the Bristol Channel.

Example No. 1 (tidal stream) - MeyGen project: This is a tidal stream project on the Inner Sound in the Pentland Firth, Scotland, which is expected to have a final output of around 398 MW [13]. It is the largest fully permitted tidal stream project in Europe and is considered a flagship project for the industry. In this project, horizontal turbines were installed on the seabed [13].

Example No. 2 (tidal range) - Bristol Channel: The actual project is called Swansea Bay Lagoon. There are other good positions for several tidal power plants in the Bristol Channel bay. Swansea Bay Lagoon is the first project of its kind in the world, and will eventually have a capacity of about 240 MW [14]. The area covered by the lagoon is about 11.5 km^2, for which a wall about 9.5 km long will be built an average of 3.5 m above the water level [7].

In this work, there are points that have not yet been sufficiently covered, such as optimization through smoother surfaces of the wings to reduce marine fouling or possibilities to increase the kinetic potential by increasing the height difference. As can be seen, there are many more possibilities for further investigations.

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