Wells turbine: the state of the art

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Abstract

The first oscillating water column was invented in 1940. In the past decades the need of wave energy systems has significantly increased. This article quickly describes the Wells turbine and possibilities to enhance its performance and should answer the question: what are the design parameters that can be optimized? Furthermore it gives a small outlook about the history of oscillating Water Columns.

Keywords: wells turbine, owc, energy, oscillating water column, optimization

1 Introduction

In comparison to wind and solar power, ocean waves are continuously produced around the day. They vary in height and by that in potential of power. The ocean as a source of renewable energy has big potential regarding the fact that energy can be produced around the clock. Furthermore waves travel large distances without loosing significant amounts of power, which makes them efficient as an energy transport mechanism. To make use of this potential different devices were invented using the converting the wave energy to drive electrical generators. The devices are differentiated by the water depth in which they used to be built. Another way to sort the devices is to differentiate them by their principle of working.
Most of the devices, named as oscillating water columns, short OWC, are installed near the shore or on the shoreline. The benefits are easier installation and maintenance, because of the fact that long underwater cables are not necessary. Its also possible to built floating or fully submerged devices to use the most powerful wave systems available. The downside is the more complex part of the installation, maintenance and the problem of mooring the device.
To use the power of waves properly there needs to be an efficient and economical way. The solution is the Wells turbine [1].

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2 Oscillating water columns

2.1 What is an oscillating water column?

Oscillating Water Columns, or short OWC, are devices which mainly convert wave energy. They use the absorption of wave energy and convert it into air pressure to infuse a generator with power, through a linked turbine. OWC functions as followed: a hollowed shell below the sea traps the inner water surface. Through wave energy, the air inside the shell compresses and decompresses. The air now moves through a turbine which is linked with a generator. The operating chain behind this process is shown in Figure 1 and Figure 2.

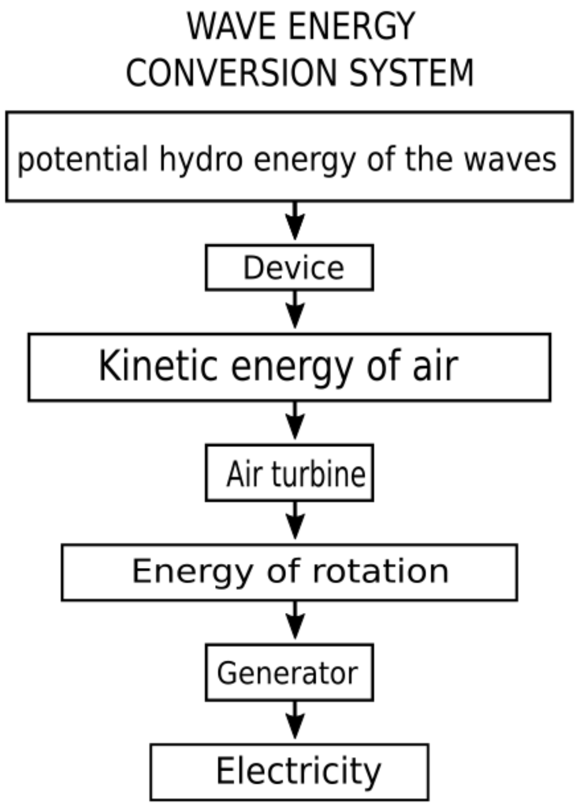

Fig. 1: Example of wave energy conversion operation chain

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2.2 History of Oscillating Water Columns

The first appearance of wave energy conversion (WEC) was published by Yohsio Masuda, born in 1925 and died in 2009, a navy officer from Japan, in the second half of 1940. Masuda invented a navigation buoy powered by wave energy. It was later named as a (floating) OWC. Buoys like these used an unidirectional air turbine with a system of rectifying valves. These kind of Buoys have been used in Japan, since 1965, and later in the USA. An example of this buoy is shown in Figure 3.
The first big water energy converter which was deployed into the sea was Kaimei, also invented by Masuda. It was built by the Japan Marine Science and Technnology Centre (JAMSTEC), weighing 820 ton with dimensions of a length of 80 m and a width of 12 m. It consists of thirteen OWC open bottom chambers each having a water plane area of 42 m^3-50 m^3 and was set off the western coast of Japan in 1978-1980.
After the oil crisis about 1973, Europe studies to develop large scale WECs. The aim was to build a large two GW wave energy plant, but without success. The National Engineering Laboratory (NEL) from Scotland was invented different concepts for one big OWC Plant. Without any built prototype the british programme was terminated in 1982. With the decision, made in in 1991 by the European Commission, of including wave energy in the research and development program on renewable energies the situation changed and lead to studies, followed by construction of two OWC plants. One was built in Portugal on the island of Pico, the other in Scotland on the Island of Islay. Both plants utilizes Wells turbines to drive the generator. Pico plant was completed in 1999 with a rating of 400 kW and still operational. Islay plant was completed in 2000 with a rating of 500 kW [2].

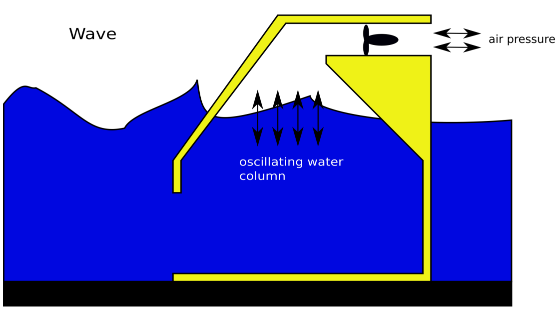

Fig. 2: Principle of the OWC

2.3 Wells Turbine

The Wells turbine, named by the inventor Professor Alan Wells of the Queens University of Belfast in the 1980s, is an axial flow turbine. It's used as an economical and efficient solution to convert the en-

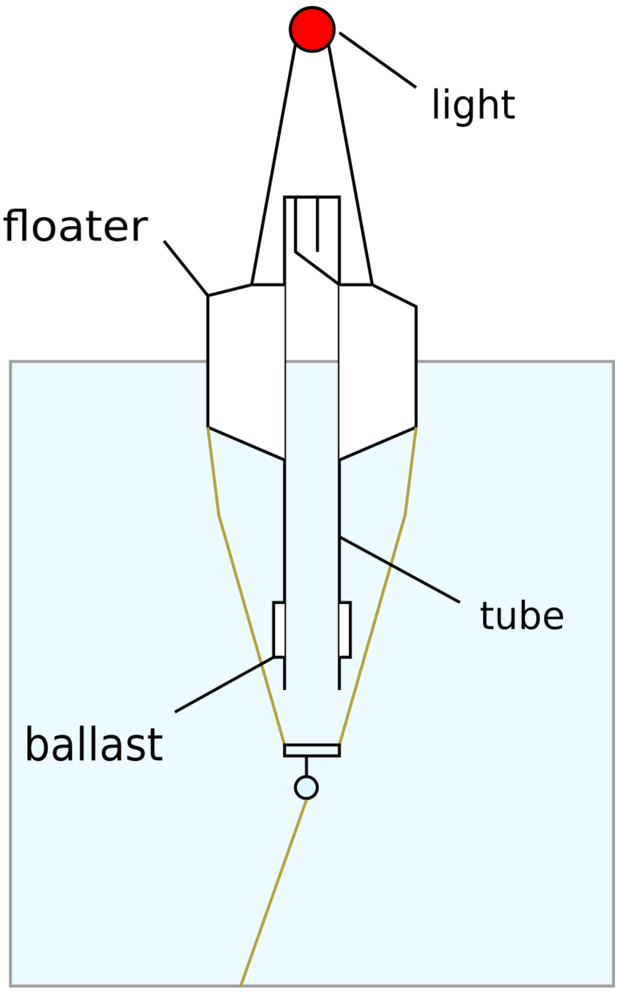

Fig. 3: Example of Masudas floating buoy.

ergy of oscillating flow motion to drive an electrical generator. It contains a rotor with untwisted airfoil blades. Because of this the turbine rotates in one direction, regardless the bi-directional air flow [1]. The simplest form of the Wells turbine consists of symmetrical aerofoil blades around a hub with their chord planes normal to the axis of rotation. The turbine can have guide vanes on both sides of the rotor [3]. The operation cycle of Wells turbine is differentiated into two stages because of the mechanism of OWC. The first stage is the compression. The water level inside the housing rises and pushes the air inside through the turbine. The aerodynamic force F_R due to push and pull forces is given by

$$F_R = \sqrt{L^2 + D^2} \tag{1}$$

This force can be seperated in two components, axial and tangential directions as

$$F_A = L \; cos \; \alpha + D \; sin \; \alpha \tag{2}$$

$$F_t = L \; sin \; \alpha - D \; cos \; \alpha \tag{3}$$

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where F_A and F_t are the axial and tangential forces. In the stage of pulling, in which the water level drops, air is sucked into the duct. It's also shown that in either stage there is just one direction for the rotor to move. That's because of the tangential Force. It remains in the same direction for both positive and negative values of α [1].

3 Performance parameters

There are several parameters that affect and influence the design and performance of Wells turbines. Typical drawbacks of Wells turbines are low tangential force, which are leading to low power output. Another one is the low aerodynamic efficiency.This section deals with solutions to overcome disadvantages and aims at improving the performance.

3.1 Guide Vanes

One option to improve the performance of a wells turbine is to delay the airfoil stall. To achieve this, guide vanes can be installed on the rotors hub. These vanes are used to reduce the swirl losses at the turbine exit. [1].

3.2 Hysteretic behaviour

Because of reciprocating flow there is a hysteretic loop in the performance of the Wells turbine. Those Characteristics are produced and affected by the differential pressure caused by different behaviour of waves between push and pull stage [1].

3.3 Multi-plane Wells turbine

It's possible to use multi-planes for Wells turbine. This is useful for high pressure values. These kind of concepts avoid using guide vanes, which results in less maintenance and repair. A multiplane turbine without guide vanes is simple to design but less efficient than with it. There is the possibility to build a turbine with two twin rotors rotating in opposite direction to use the swirl energy at the exit. It also has no guide vanes. [1].

3.4 Flow through Wells turbine

The aim is to design a turbine that has high aerodynamic efficiency and is matched with the OWC system for pressure drop and flow rate, regarding the wide range of sea conditions. The efficiency of aerodynamics increases with flow ratio up to a critical value. It decreases at a turning point. To avoid transonic effects the maximum Mach number on the blades should be less than the critical Mach number.

4 Comparison with other turbines

A lot of self-rectifying air turbines have been improved over the years. Another yet potent turbine is the impulse turbine. It has the potential to be superior to the Wells turbine in overall performancs under irregular flow conditions. Simulations show, that the new biradial impulse turbine has exhibit an overall device performance (71 % efficiency) better than that of a multi stage Wells turbine. It also got the advantage of smaller rotor diameter.

5 Optimization of design

This sections aim is to show methods to optimize the design of Wells turbine to enhance overall performance. Methods are: blade dimension or position, adding a plate on the blade or by creating new blades. Examples of optimization methods are shown in Figure 4.

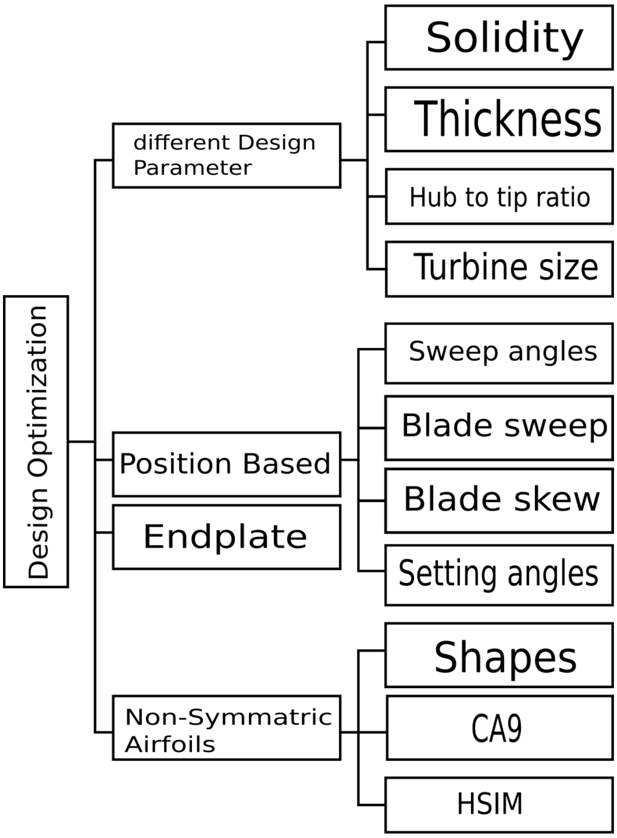

Fig. 4: Design optimisation categories and subcategories.

5.1 Solidity

The prediction methods and the variables that affect the aerodynamic performance of a Wells turbine are discussed in [4]. The increase in blade thickness leads to a larger negative value of torque coefficient, but has

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a favorable effect on starting. Thicker blade profiles are preferred for small scale turbines, whether thinner profiles are for large-scale turbines. A large solidity is need to self-start the turbine. With the optimal size of turbine, the simulation results in an improvement of 5 % in power output.

5.2 Position based parameter

Changing the position of blade according to the hub center line has a direct effect on performance.
A comparison was made to investigate the aerodynamic performance of backward swept and unswept angle blade for different solidities (σ=0.64 and σ=0.32) for the pitch angles 0° and 20°in [5]. In result: 0° setting pitch angles have shown that the swept back angle blade produces a more positive value of efficiency but at an expense of peak efficiency.

There was an experiment to investigate the influence of the blade sweep ratio on the performance of Wells turbine. In a quasi-steady analysis found in [6], it was found out that blade sweep influenced the performance of Wells turbine. A suitable choice for sweep ratio is 35%.

5.3 End plate

To improve the performance even more there is the option to install an end plate on the blade. Using an experimental model and CFD method [7], results in that the optimal position of the plate is a forward type. It results in an enhancement of peak efficiency of 4 % in comparison to a Wells turbine without the end plate on the blade.

6 Conclusion

This article is a short summary of the state of the art of the Wells turbine. Within this article it's shown, that there are a lot of parameters to look for, which improve and impact the overall performance of the Wells turbine. Most of them are design parameters that have lot of potential for optimization. The following remarks can be concluded:

- Components of Wells turbine are important for performance and efficiency. To harvest the most out of this turbine a lot of optimization in parts is needed
- Guide Vanes and multistage Wells turbines which rotate unidirectional are used to increase the efficiency
- Optimum position of an end plate, optimum value of blade sweep ratio, blade skew and pitch angle increase the efficiency even more

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