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Wave energy conversion: Design and shape optimization

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ABSTRACT

Modified Wells turbines allow an efficient use of the power contained in the ocean and sea waves. The present study introduces the performance of an axial turbine which called Wells turbine. This turbine is used in oscillating water column (OWC) wave energy conversion devices. This type of axial turbine is investigated through numerical analysis and optimization. Unsteady 3D Reynolds-averaged Navier-Stokes equations were solved with *k-ω* SST turbulence closer model. A comparative study of optimized and conventional blades with steady and unsteady flows has been presented. For shape optimization, blade profile-thickness and sweep modifications along with and without grooved-casing, (GC) designs are considered. The results concluded that the reference blade with GC performs better in terms of torque coefficient and efficiency if the flow is attached. The unsteady flow gives a stream-wise circulation near the blade suction surface. The groove changes the tip vortex and helps to suppress the flow separation. In addition, the effect of blade sweep, profile variation and groove depth on the hysteresis behavior of the Wells turbine has been investigated in this work.

1. Introduction

In 1976, Professor Wells of the Queen's University of Belfast proposed a self-rectifying axial flow air turbine suitable for the OWC. The turbine is called Wells turbine. In its simplest form, the air turbine rotor consists of several symmetric airfoil blades positioned around a hub as shown in Fig. 1a. Because of simplicity in design, the turbine has been widely applied for wave energy conversion and an important amount of research and developments have been done in many countries.

Many research programs attempting to garner energy from sea waves depend on the Oscillating Water Column (OWC) as the energy converter mechanism (Keskin Citiroglu and Okur, 2014; He et al., 2013; Ning et al., 2016). In such a mechanism, the water-wave energy is converted to pneumatic energy in the air, which flows reciprocally across a self-rectifying axial air flow turbine, called a Wells turbine.

The Wells turbine is an axial flow and self-rectifying, works on the bidirectional flow and produces unidirectional shaft rotation. Several researchers studied steady and unsteady behavior of this turbine to predict the performance (Brito-Melo et al., 2002; Raghunathan, 1995; Torresi et al., 2008; Halder et al., 2015; Taha et al, 2010). The turbine has disadvantages such as low efficiency, poor starting characteristics and low power output. Hence, it is required to redesign the turbine to improve its output power and aerodynamic efficiency in wider wave variability.

References (Kim et al., 2001; Inoue et al., 1986a) reported the performance of the turbine based on starting and running characteristics, and modified blade solidity, setting angle, tip-to-chord ratio, etc. The solidity has a higher performance sensitivity than that of the setting angle or the tip-to-chord ratio (Setoguchi et al., 1998, 2003). The performance of the turbine varies during inhaling and exhaling of the air (Puddu et al., 2014) and is better during the outflow phase compared. Kim at el (Kim et al., 2002a).reported the effect of blade thickness and angle of attack and found hysteresis characteristics under sinusoidal flow conditions. The blade thickness and the angle of attack were more effective on the turbine performance than the setting angle and the gap-to-chord ratio. Shabaan (Shaaban, 2016a, 2016b) numerically optimized the performance of Wells turbine with rotor radial solidity distribution. Das et al. (Das et al., 2017). discussed different type OWC device and optimization techniques. The results indicated that the optimized geometry enhanced better performance than others.

The anticlockwise hysteresis loop in the decelerating flow leads to a flow separation on the suction surface (SS) near the hub, whereas the clockwise hysteresis loop in the in the accelerating flow is related to the separation on the suction surface near the tip (Kinoue et al., 2003, 2005). The second law efficiency and entropy generation characteristics for the blade with NACA0015 profile under unsteady flow showed better than

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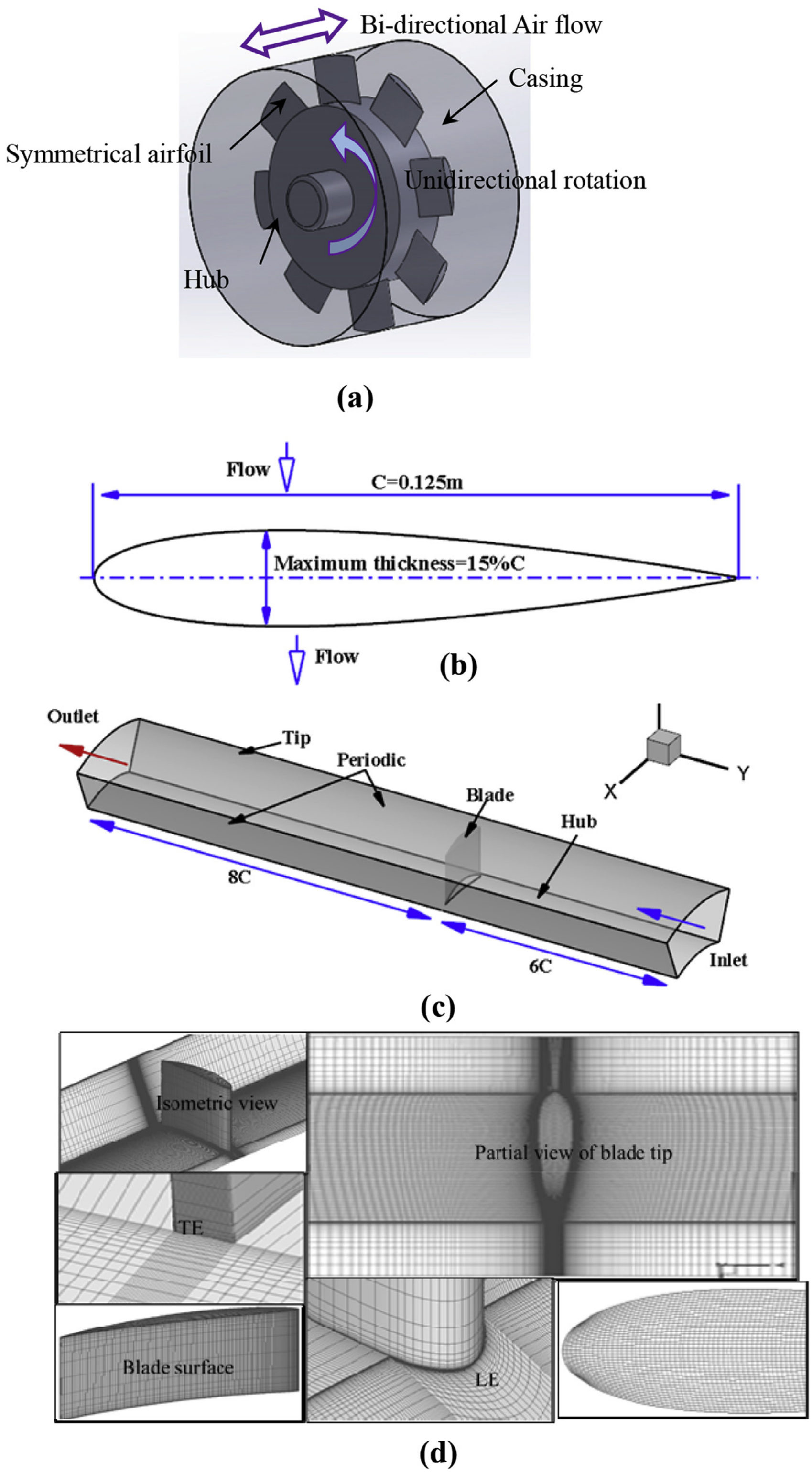

Fig. 1. (a) Wells turbine rotor; (b) Configuration and dimension of rotor; (c) Computational domain; (d) Mesh on the different surfaces.