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Performance investigation of an innovative vertical axis turbine consisting of deflectable blades

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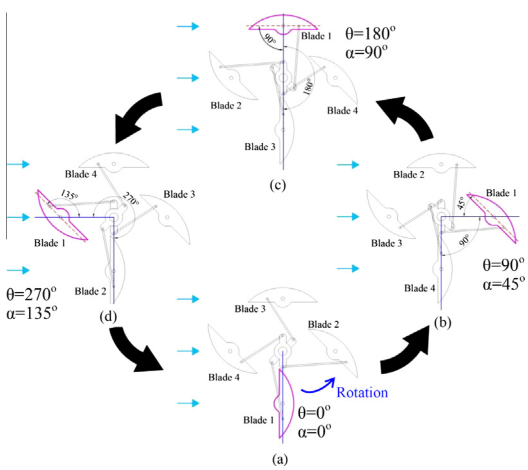
HIGHLIGHTS

- The analysis of an innovative vertical axis turbine consisting of deflectable blades is depicted.
- The analyses of deflectable-blades turbine are proposed experimentally and numerically.
- The detailed characteristics of DBT are investigated as it is driven by water current.
- The maximal performance improvement from traditional FBT to new DBT is 41.1%.

GRAPHICAL ABSTRACT



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ABSTRACT

The aim of this study is to investigate the performance of an innovative vertical axis turbine which possesses the blade-self-deflection function for ocean current and tidal energy application. The blade deflection is accomplished by interaction of blades and related mechanisms as the turbine rotates. To enhance the turbine performance, it is designed that the blade deflection not only increases the power output for a downstream blade, but also decreases the resistance for an upstream blade. The observation of the prototype in laboratory flume is displayed to validate the feasibility. Furthermore, a commercial code is employed to analyze the turbine performance. The velocity and pressure contours of the calculation domain are simulated to obtain the torque and power output of deflectable-blade turbine. Moreover, the results of performance analysis are validated by the experimental data.

The detailed flow field analysis and hydrodynamic characteristic are reported as deflectable-blade turbine is driven by the water stream. The results show that the maximum and minimum total torque for this turbine occur at $\theta = 45°$ and $\theta = 75°$, respectively as it rotates one-quarter turn. In performance comparison, the maximal power coefficient of the deflectable-blade turbine is 41.1% higher than that of traditional vertical axis turbine with fixed blades for stream velocity of 1 m/s. Furthermore, the correlations of optimal angular velocity and maximal power output for the deflectable-blade turbine are obtained for current velocity from 0.6 m/s to 2.2 m/s for hydropower applications.

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Nomenclature

B	breath of the blade, m
C_P	power coefficient
H	height, m
L_L	long connecting rod, m
L_S	short connecting rod, m
N	section number of each quarter revolution
p	pressure, pa
P_{out}	power, W
Q	torque, N-m
R_B	the distance between pin of connecting rod and deflection center, m
R_C	rotating radiuses of DBT, m
R_L	deflection radiuses of blades, m
R_r	rotating radiuses of the ring, m
V_0	averaged velocity, m/s

Greek symbols

α	deflection angle of blade, °
θ	rotation angle of entire DBT, °
ρ	density, kg/m^3
ω	angular velocity of the DBT, rad/s

Subscripts

avg	average
max	maximal
opt	optimal

Acronyms

TSR	tip speed ratio
DBT	deflectable-blade turbine
FBT	fixed- blades turbine

1. Introduction

Recently, the issues of energy shortage and environmental protection have become important topics for energy utilization. Exploiting renewable energy from ocean is one of important ways to reduce carbon dioxide emission. Ocean current and tidal energy, which are significant renewable energy, are predictable and continual. Superior performances of turbines are essential for extracting ocean current and tidal energy. With regard to ocean hydrokinetic power utilization, horizontal and vertical axis turbines are two basic types for current energy conversion by the rotation of blades [1]. Furthermore, the vertical axis turbine, driven by multi-directional current flow which is perpendicular to the turbine axis, has been widely applied in current energy conversion [2].

Many researchers have adopted various techniques to improve the performance for the vertical axis turbine. To increase power generation from current energy, a new vertical axis turbine adopting a cyclical blade system that actively controls the rotor blades for improved turbine efficiency was revealed by Hwang et al. [3]. In their optimal results, the performance of the turbine achieved approximately 70% better performance than that of a fixed pitch turbine. Another innovative vertical axis turbine applied a central deflector for the collection of energy from river and tidal current was investigated by Amelio et al. [4]. Their preliminary performance estimations revealed that the efficiency of the turbine was about 43% in optimal conditions. Furthermore, to improve the autorotation characteristics, novel designs of vertical axis turbine consisted of several flapping blades demonstrated experimentally [5,6]. Moreover, the three-dimensional analyses of performance investigations for the novel turbine were reported numerically [7]. In addition, a new water turbine, which was constructed on the water turbulence principle without using any blade, was investigated by Beran et al. [8] utilizing the low water gradient water sources. Furthermore, to overcome the limitation of starting and to increase performance, a novel vertical axis turbine with flexible foils for self-starting was designed by Zeiner-Gundersen [9]. Then, Chong et al. [10] studied the performance enhancement of a vertical axis turbine containing a guide vane for wind energy utilization. An innovative vertical axis autorotation turbine, which allowed vertical flat plate to rotate freely around a vertical axis, was revealed by Fernandes and Bakhshandeh [11] to harvest the energy from the current. In addition, Jing et al. [12] investigated experimentally the performance improvement of tidal current vertical axis turbine with variable-pitch blades. Moreover, the experimental results of a 3 kW three-bladed vertical axis turbine were presented by Huang et al. [13]. Their results showed that the operation speed range of water flow was narrower than that of wind. A vertical axis turbine with flexible foils was designed by Zeiner-Gundersen [9] for river, ocean and tidal applications. There experimental results showed that with a passive-blade-pitch action and limited variation in rotational speed, the performance of the turbine attained was up to 0.37 in power coefficient. Moreover, numerical and experimental analyses of vertical axis turbines with drag blades were reported [14,15]. Li and Calisal [16] analyzed the three-dimensional effects of vertical axis tidal current turbines experimentally and numerically. Furthermore, the relationships between the turbine characteristics such as power output, torque fluctuation, induced velocity, and acoustic emission of tidal current turbines related to the development of the standard were quantified [17].

The Savonius turbine is a drag type of vertical axis tidal turbine with great development potential. The rotating motion of Savonius turbine is based on the drag coefficient of a concave surface larger than that of the convex surface. Therefore, the advancing blade with concave side facing the current flow generates more drag force than the returning blade, and the torque produced by net force drives the turbine to rotate. Based on the theory, the driving torque can be increased by raising the forward force on advancing blade and reducing the reverse force on the returning blade [18,19]. A modified Savonius turbine with deflector plate was proposed by Golecha et al. [20] to enhance the power output for current energy applications. In addition, they also reported the performance improvements of two and three stage turbines experimentally. Another modified Savonius rotor without central shaft between the two end plates was investigated experimentally [21]. Three different configurations of Savonius rotors, two helical rotors with different twists angle and a straight rotor were experimentally analyzed by Ricci et al. [22]. The results depicted that rotors with helical shape and end plates had an improving effect on current energy conversion. Moreover, to raise the Savonius turbine performance, interactive flow field around two turbines were depicted by Shigetomi et al. [23] numerically. Furthermore, experimental and computational researches of Savonius hydrokinetic turbine was studied by Sarma et al. [24] to evaluate the performances as it rotates by the momentum of water current at low velocity from 0.3 m/s to 0.9 m/s. In addition, Roy and Saha [19] investigated the performance enhancement of two-bladed