A Study on Cross-Flow Hydrokinetic Turbines in Counter-Rotating Configurations

A Thesis for the Degree of Ph.D. in Engineering
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Doan, Nhat Minh
(Student ID: 81847378)

School of Science for Open and Environmental Systems
Graduate School of Science and Technology
Keio University

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Keio University

Thesis Abstract

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Registration Number	■ "KOU" □ "OTSU" No. *Office use only	Name	DOAN, Nhat Minh

Thesis Title

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Thesis Summary

Throughout a series of experimental and numerical studies, this thesis explores the possibility of implementing two cross-flow hydrokinetic turbines in counter-rotating configurations to extract marine power more efficiently compared to the conventional approach.

The first part proposed an experimental apparatus design to measure the power output of a cross-flow marine hydrokinetic turbine system operating in a laboratory water tunnel. The results of power coefficient for 8 different configurations showed the tendency of power enhancement of counter-rotating configurations due to blade interaction and increase in blockage ratio. Next, the near-wakes of all the single turbine configurations were captured and correlated with the power output. The relevant flow fields were recorded by a monoscopic particle image velocimetry technique and analyzed. The near-wake results of the single turbine cases indicated the key to refining the current design for enhancement of its power production, while serving as a baseline for comparison with twin turbines in counter-rotating configurations. Similar to the observation of the single turbine configurations, a correlation between flow field structures and the corresponding power output was later observed for twin turbine configurations. Effects of each parameter of the counter-rotating configurations were further discussed which suggested guidelines for setting up multiple devices in a power farm.

Additionally, an open-source Reynolds-averaged Navier-Stokes simulation model was presented and scrutinized for the specific turbine geometry. The model was compared with the experimental results and then used to study the turbine power output and relevant flow fields at 4 blockage ratio values. The dynamic stall effect and the related leading edge vortex (LEV) were observed. The results also gave insight into the blockage effect from a different perspective: The physics behind the production and maintenance of lift of the turbine blade at different blockage ratios. The model was then applied to counter-rotating configurations of the turbines and similar analyses of the torque production and maintenance were conducted.

Lastly, the thesis discussed the experimental capturing of the LEV structures seen in the simulation models. These experiments not only confirmed the physical existence of the LEVs but were also used to analyze the LEVs in real 3D flow fields which was not possible for the 2D computational fluid dynamics model.