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Analytical wake model of tidal current turbine

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ABSTRACT

Prediction of the wake structure is important to understand the lee flow of a tidal current turbine. The proposed analytical wake model consists of several equations derived from the theoretical works of a ship propeller jet. Axial momentum theory was used to predict the minimum velocity at the immediate plane of the lee wake and followed by the proposed recovery equation to determine the minimum velocity at various lateral sections along the rotation axis. Gaussian probability distribution was used to predict the velocity distribution of lateral sections in a wake. Entire wake is able to be illustrated through the calculation of the efflux equation, recovery equation and lateral distribution equations. Authors' previous works proposed a simplified one-dipped velocity profile and this works were being extended to predict the two-dipped velocity profile with the consideration of hub effects. The wake model is validated by using the well-accepted experimental measurements and the goodness-of-fit test. The results demonstrated that the wake model is able to predict the wake profile under various ambient turbulence conditions of TI (turbulence intensity) = 3%, 5%, 8% and 15%.

1. Introduction

OES (ocean energy system) [1] proposes the global goal to install 337 GW of tidal and wave devices by creating 1.2 millions of job opportunity and reducing 1.0 billion tonnes of carbon emission by 2050. The ambitious capacity of the ocean energy is able to attract the attentions of the policy makers, industrial players, engineers and scientists to push forward the development of ocean energy. Tidal and ocean current energy are the promising ocean energy and it is foreseeable to be a vital future energy supplies [2]. Tidal current is the flow produced due to the water rising and falling of tide and it is predictable compared to the other renewable sources [3].

The wake induced by a tidal-current turbine produces significant changes in the velocity field of the lee water region. A tidal turbine extracts kinetic energy from the flowing water through rotating hydrofoils and this process causes a velocity deficit downstream as a wake. The velocity deficit influences the performance of the turbines in tandem and thus affects the overall efficiency of tidal-current turbines in arrays. Myers and Bahaj [4] showed that proper spacing of energy extraction devices in the upstream may increase the available kinetic energy of the downstream up to 22%. Better understanding of the wake characterisation is also critical to quantify the potential effects on the sediments transport capacity. The sediment transport in the energy extraction region has negative environmental impacts [5].

Researchers carried out studies on predicting the turbine wake through the numerical and experimental methods. Sun et al. [6] used the absorption disc representing the turbine to estimate the near wake of tidal turbine. Myers and Bahaj [7] investigated the wake behaviour when the disc was placed closer to the floor. Harrison et al. [8] conducted CFD (computational fluid dynamics) simulation using a homogeneous coupled volume-of-fluid approach and compared to the experimental results of Myers and Bahaj [7]. Maganga et al. [9] measured wake profile of a three-bladed turbine and the results suggested that the ambient turbulence intensity affect wake recovery rate. Mycek et al. [10] continued the study of Maganga et al. [9] by investigating the interaction between two tidal turbines. Bastankhah and Porté-Agel [11] proposed an analytical model to predict the wake structure of a wind turbine by using conservation laws.

Lam and Chen [12] proposed two equations to predict the efflux velocity and its lateral velocity distribution at various cross sections along the rotation axis. Efflux velocity is the minimum

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